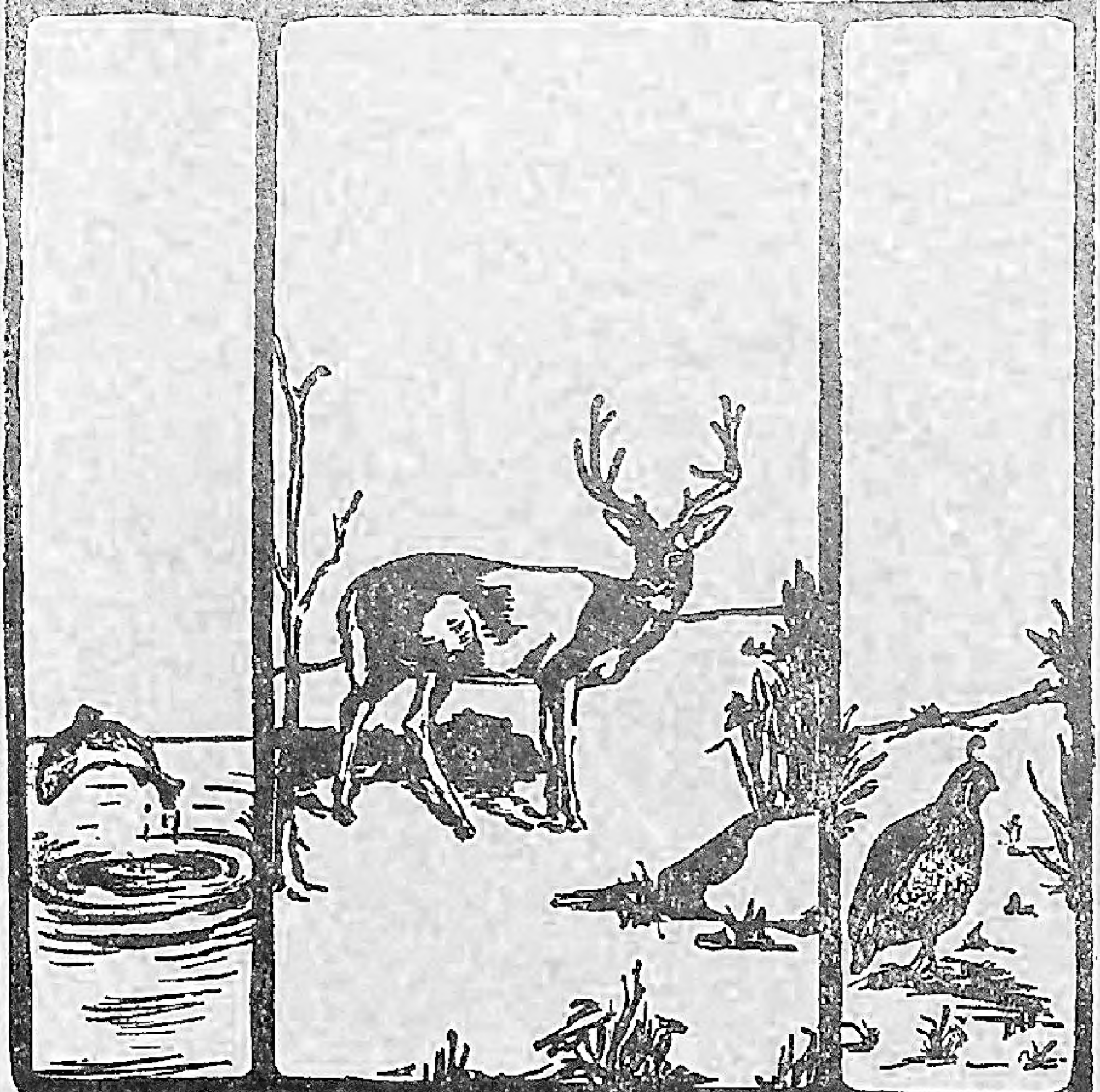
CALIFORNIA FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 59 JANUARY 1973 NUMBER 1



California Fish and Game is a journal devoted to the conservation of wildlife. If its contents are reproduced elsewhere, the authors and the California Department of Fish and Game would appreciate being acknowledged.

The free mailing list is limited by budgetary considerations to persons who can make professional use of the material and to libraries, scientific institutions, and conservation agencies. Individuals must state their affiliation and position when submitting their applications. Subscriptions must be renewed annually by returning the postcard enclosed with each October issue. Subscribers are asked to report changes in address without delay.

Please direct correspondence, except regarding paid subscriptions, to:

CAROL M. FERREL, Editor
California Fish and Game
987 Jedsmith Drive
Sacramento, California 95819

Individuals and organizations who do not qualify for the free mailing list may subscribe at a rate of $2 per year or obtain individual issues for $0.75 per copy by placing their orders with the Office of Procurement, Documents Section, P.O. Box 20191, Sacramento, California 95820. Money orders or checks should be made out to Office of Procurement, Documents Section. Inquiries regarding paid subscriptions should be directed to the Office of Procurement.

CALIFORNIA FISH AND GAME

VOLUME 59 JANUARY 1973 NUMBER 1

Published Quarterly by

STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF FISH AND GAME

CONTENTS

Calif. Fish and Game, 59(1): 5–35. 1973.

RELATIONSHIPS BETWEEN SOIL SALINITY AND THE SALINITY OF APPLIED WATER IN THE SUISUN MARSH OF CALIFORNIA[1]

GLENN L. ROLLINS
Wildlife Management Branch[2]

California Department of Fish and Game

The relationship of soil salinity to the salinity of applied water was studied in two separate but related investigations in California's Suisun Marsh. Soil salinities and surface water salinities were monitored on study plots located throughout the area. Part I of this investigation was conducted on four private duck clubs under water management practices typical of those used throughout the marsh. Part II was conducted in a test pond where water management and surface water salinities were controlled.

A significant correlation existed between the salinity of applied water and the salinity in the first and second feet of soil. The flooding of marsh soils with highly saline water, under present marsh management practices, would greatly increase existing soil salinities. The leaching of marsh soils by alternate flooding and draining with low salinity water was an effective means of reducing soil salinity.

The type of water management practiced by the duck clubs studied produced extremely high soil salinities which inhibit the production of valuable waterfowl food plants. Leaching is recommended as a general practice in Suisun Marsh to reduce soil salinity and enhance the production of the more important waterfowl food plants.

INTRODUCTION

The Suisun Marsh consists of approximately 80,000 acres of marshlands, sloughs and bays. It represents nearly 10% of the remaining natural wetlands in California. The Suisun Marsh is a critical waterfowl wintering area and in drought years has harbored as much as 20% of the ducks wintering in the state. The marsh contains the 10,487 acre Grizzly Island Waterfowl Management Area and well over 150 privately-operated duck clubs. Duck hunting accounts for approximately 150,000 man days of recreation yearly.

In July of 1961 the Delta Fish and Wildlife Protection Study began an investigation of the ecology of the Sacramento-San Joaquin estuary in California in relation to state and federal water development programs. The State Water Project, expansion of the federal Central Valley Project, and continuing upstream water development by local entities will reduce fall and winter outflow from the Sacramento-San Joaquin Delta. This reduction will increase the magnitude and duration of saline water in the channels and bays surrounding the Suisun Marsh, in turn causing an increase in the salinity of water applied to the land.

[1] Accepted for publication July 1972.
[2] Formerly with the Delta Fish and Wildlife Protection Study.

The purpose of the Suisun Marsh investigation was to determine the effect of future upstream water development upon the ecology of the marsh. The answers to three broad questions were required to help define these effects and subsequently to protect the marsh environment.

1) What are the relative values of the various marsh plants as duck foods?
2) What influences do soil salinity and other factors have on the distribution and growth of marsh plants?
3) What is the relationship between channel water and soil salinity?

Mall (1969) reported on the first two questions.

The purpose of the present investigation was to answer the third question—the relationship between soil salinity and the salinity of applied water—with the objective of determining the quality of water required for proper management of the marsh. A firm understanding of the soil-water salinity relationship is essential before measures can be implemented to protect or enhance the marsh environment under future water conditions.

This report describes the field procedures and results from two separate studies:

1) A program in which soil salinity fluctuations were monitored on four privately-owned and operated duck hunting clubs.
2) A controlled experimental procedure in which saline water was applied to a test pond and resultant soil salinity fluctuations were monitored.

This study was a cooperative venture between the California Department of Fish and Game and the California Department of Water Resources and was funded under the California Water Bond Act.

Part I

GUN CLUB SOIL STUDY

The purpose of this phase of the Suisun Marsh investigation was to determine the salinity response of soils to the normal applications of slough water as applied under routine management conditions. This water was drawn by the clubs from sloughs adjacent to the study areas. The quality of the water was enhanced by periodic releases of fresh water by the U. S. Bureau of Reclamation from Lake Berryessa via the Putah South Canal.

Study Area

Four gun clubs, located west of Suisun Slough (Figure 1) were chosen as study sites in June of 1967. The sites selected represented the extreme and intermediate positions of a salinity gradient within the reaches of Suisun Slough which were influenced by the Bureau of Reclamation's freshwater releases in 1965 and 1966. Unfortunately, high outflows during the 1967–68 water year (October 1, 1967 to September 30, 1968) reduced the channel salinity differences between gun clubs from an expected 5‰ (parts per thousand) to a mean difference of 1‰.

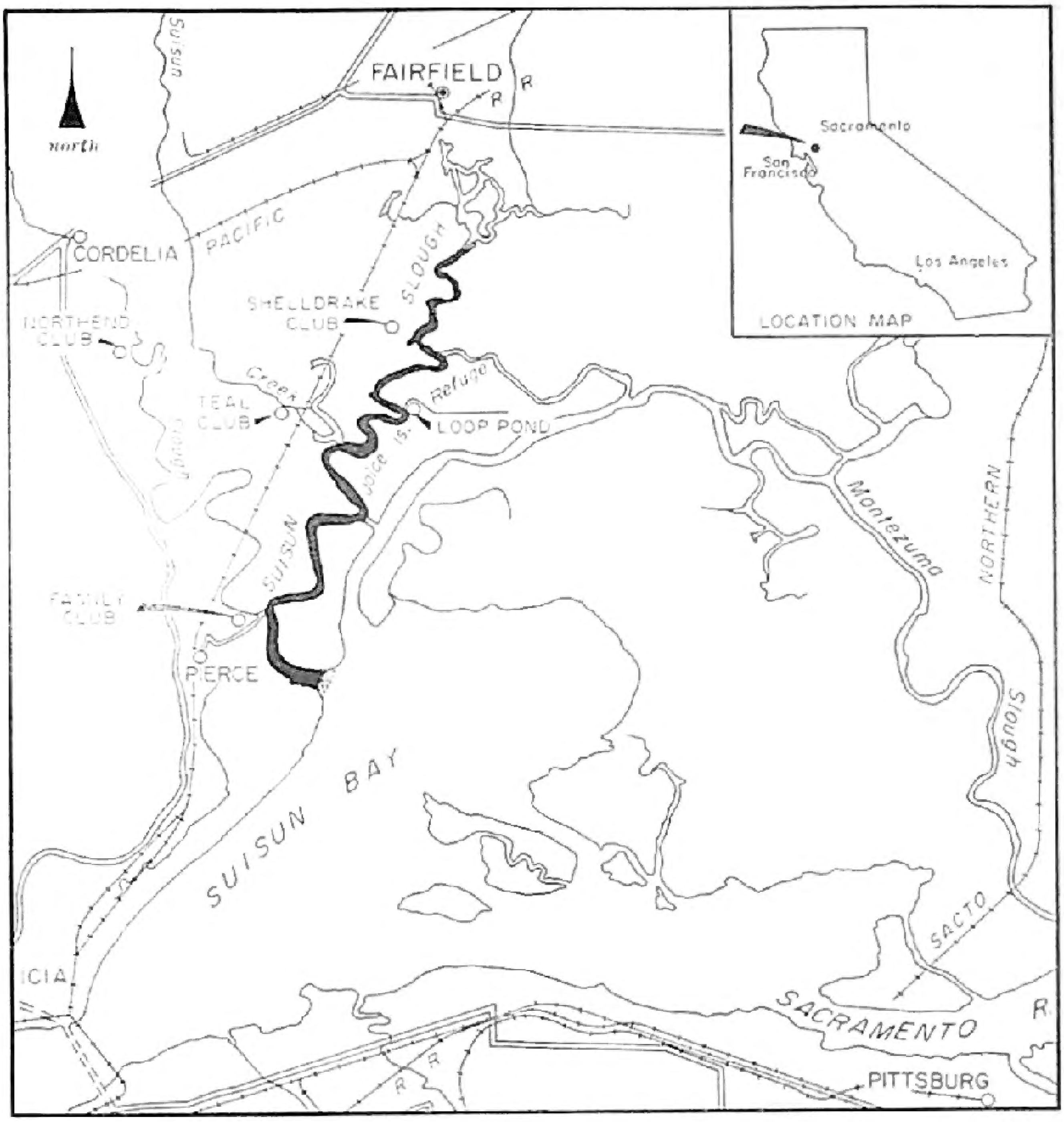


FIGURE 1. Test site locations.

Soils

The soils of each gun club were classified according to criteria adopted by the U. S. Soil Conservation Service during a 1965 soil survey of the marsh. Suisun Marsh soils were separated into four types, distinguished mainly by the percentage of organic matter they contained (Table 1). No measurements of organic content were made during this investigation. However, soil moisture was monitored and organic content was estimated by using the previously determined relationship between moisture retention and organic matter (Mall, 1969). Other physical and chemical soil characteristics described by the U. S. Soil Conservation Service were also used in the soil classification of the area.

The soil of the Northend Duck Club study pond was nearly homogeneous and was easily classified as the Reyes type. While flooded, the soil was a very dense, sticky, gray clay containing only traces of organic matter. As would be expected of soil low in organic matter,

TABLE 1. Characteristics of Suisun Marsh Soils *

Soil name	Percent organic matter	Percent of marsh by area	Soil profile (dry)			Natural drainage	Subsoil permeability	Fertility	Present use
			Surface layer	Subsoil	Parent material				
Suisun-Joice association									
Suisun	50-70	9	Black peaty muck, very acid, very strongly saline.	Black peaty muck, very acid, very strongly saline.	Black decomposing material, moderately, alkaline, very strongly saline.	Very poor	Moderately rapid	Low	Wildlife and pasture
Joice	30-50	28	Black muck, stratified with light gray clay, very acid, strongly saline.	Black muck stratified with light gray clay, very acid, strongly saline.	Black muck with gray clay, moderately alkaline, strongly saline.	Very poor	Moderately rapid	Low	Wildlife and pasture
Reyes-Tamba association									
Tamba	15-30	28	Mottled gray clay and black muck, very strongly acid, strongly saline.	Mottled gray clay and black muck, very strongly saline.	Gray clay and black peat, moderately alkaline, strongly saline	Very poor	Moderate	Low	Wildlife and pasture
Reyes	2-15	20	Mottled gray clay, extremely acid, strongly saline.	Mottled gray clay with lenses of black muck, extremely acid, strongly saline.	Mottled gray clay with thin lenses of black muck, moderately alkaline, strongly saline.	Very poor	Slow	Very low	Wildlife and pasture

* Unpublished data—U.S. Soil Conservation Service soil survey, 1965.

soil moisture at saturation was quite low when compared to more organic marsh soils (Table 2). Following several months of draining, the pond bottom became extremely hard and cracked throughout the first 8 inches.

The soils sampled on the Shelldrake Duck Club were nearly homogeneous. Shelldrake soils, classified as the Suisun type, were quite loose and contained a very high percentage of organic matter. Accordingly the percent soil moisture at saturation was much higher than the other clubs (Table 2). In some instances it was difficult to obtain samples due to the liquid nature of these soils. This soil type did not crack during the period the pond was dry.

Soils of the Teal and Family duck clubs were Joice type. The physical characteristics of these soils were intermediate between the highly organic muck of Suisun type and the dense inorganic clays of Reyes type. The soils of these clubs probably contained between 30 and 50% organic matter. They were black, mottled with gray clay and their texture was a clayey muck. When dry, the pond bottoms were laced with cracks. Cracks on the Teal Club were numerous and 3 to 5 inches deep. The Family Club had fewer cracks, but several were 2 to 3 ft deep.

The three classifications of soils encountered during this part of the study represent approximately 57% of all soils in the marsh (Table 1). An additional 28% are Tamba type which were studied at length in the second part of this study. The remaining 15% are agricultural soils and are on Grizzly Island and around the perimeter of the marsh.

Vegetation

The dominant plant on the Northend Club was pickleweed (*Salicornia* sp.). It comprised approximately 75% of the vegetation in the pond. Adjacent to a continuous leak in the pond levee was a nearly pure stand of Olney bulrush (*Scirpus olneyi*). Bordering the Olney bulrush, but extending farther out into the pond, was a stand of alkali bulrush (*Scirpus robustus*). These two plants were found only in the vicinity of the leak. Monthly soil salt concentrations were substantially lower at the site near the leak than anywhere else in the pond. Plants at the water's edge and on the levees were: brass buttons (*Cotula coronopifolia*) and miscellaneous upland herbs like fat hen (*Atriplex patula*), dock (*Rumex* sp.), wild radish (*Raphanus sativus*), and various grasses.

The Shelldrake study pond was about half bare ground and half pickleweed. Around the perimeter of the pond, on slightly higher ground, were dense stands of saltgrass (*Distichlis spicata*). Levee vegetation was upland herbs and grasses. No alkali bulrush was observed in this pond.

For the most part, the pond bottoms studied on the Teal and Family gun clubs were bare due to discing; however, adjacent areas inside the levees supported alkali bulrush and pickleweed in about equal proportions. Again, the higher, better-drained areas were vegetated with miscellaneous upland herbs and grasses.

Methods and Sampling Procedures

Water manipulation on the Shelldrake, Teal and Family Clubs followed the same regime used by the majority of duck clubs in the Suisun

TABLE 2. Soil, Salt and Water Quality Conditions Observed on the Individual Gun Clubs from July 1967 to July 1968 *

Club name	Percent soil moisture when saturated	Relative soil organic matter†	Relative soil salt amounts ($Ec \times 10^{-3}$)		Soil salt concentration (°/oo TDS)		Mean pond water quality (°/oo TDS)‡	Mean channel water quality (°/oo TDS)‡
			Hi-low	Percent reduced	Hi-low	Percent reduced		
Shelldrake	348	4.4	44–18	59	116–17	85	2.6	1.7
Teal	242	3.1	44–21	52	146–28	81	3.7	2.0
Family	223	2.8	21– 7	67	80–12	85	3.5	2.6
Northend	79	1.0	12– 6	50	85–24	72	2.5	0.9

* Table values represent only the 0 to 8-inch level.
† Values are relative and based on assumption of positive relationship between soil moisture levels and soil organic matter content.
‡ Correspond to period from October 1967 to February 1968 during which the ponds were flooded and water was being drawn from the channels into the ponds for circulation.

Marsh. Ponds were flooded from adjacent sloughs in mid-September prior to the duck hunting season. Water was circulated continuously thereafter until end of the hunting season in mid-January. The water then was drained from the ponds. The soil surfaces dried by March except in isolated low areas.

The Northend Club was flooded in mid-September, but draining was not begun until the first of March. Consequently surface water was present on the pond through May.

Twenty stations were established along a transect within a selected pond at each of the gun clubs. Samples of surface water and soil were collected monthly at each station for a 12-month period beginning July 1967 and ending July 1968.

At each flooded plot the water depth was measured and a 4-oz sample of water collected. A conductivity bridge was used to determine the electrical conductivity of each sample and these values were then converted to parts per thousand total dissolved solids (TDS).

Soil samples were taken at the 0–8, 8–16, 20–28, and 32–40 inch levels at each station. Samples were removed by a soil auger. Surface water was skimmed off and the samples were sealed in plastic bags for laboratory processing.

The procedure used to analyze soil samples was identical to that used by Mall and consisted of standard techniques (U.S. Salinity Laboratory staff, 1954) for gravimetric soil moisture determination and soil salinity based on the conductivity of 1:5 soil water extracts.

Relative amounts of salt were based on the conductivities of the 1:5 solutions and expressed as millimhos. Monthly means of the relative salt amount at each sampling depth were calculated for each study plot.

Results and Discussion

The interrelationship between soil moisture, the amount of salt in the soil, and soil-salt concentration can be expressed by the equation:

$$\text{Soil Salt Concentration} = \frac{\text{Amount of Salt}}{\text{Soil Moisture}}$$

The movement of soil salts followed a well-defined cyclic pattern through the year (Figure 2). These fluctuations were related to soil moisture and were therefore largely determined by water management. As would be expected, there was an inverse relationship between soil moisture and soil salt amounts and concentration in the first 8 inches of soil. Mall (1969) described this cyclic rise and fall of salts in the soil profile and found it closely related to soil moisture.

Salt concentrations in the first 8 inches of soil were highest in September. The high concentrations resulted from the 6-month period during the spring and summer that the ponds were dry. Two factors contributed to the high concentrations: (i) soil moistures were at their lowest and (ii) additional salt presumably was brought up into the surface layer from lower levels by the processes of evaporation and transpiration. Sampling showed that at the 20–40 inch level the amount of salt was relatively high in all soil types and that in contrast to the 0–8 inch level, varied only slightly throughout the year (Figure 3).

Mall (1969) recorded that the highest soil salt concentrations in the 0–12 inch level occurred in September when ". . . soil moisture was

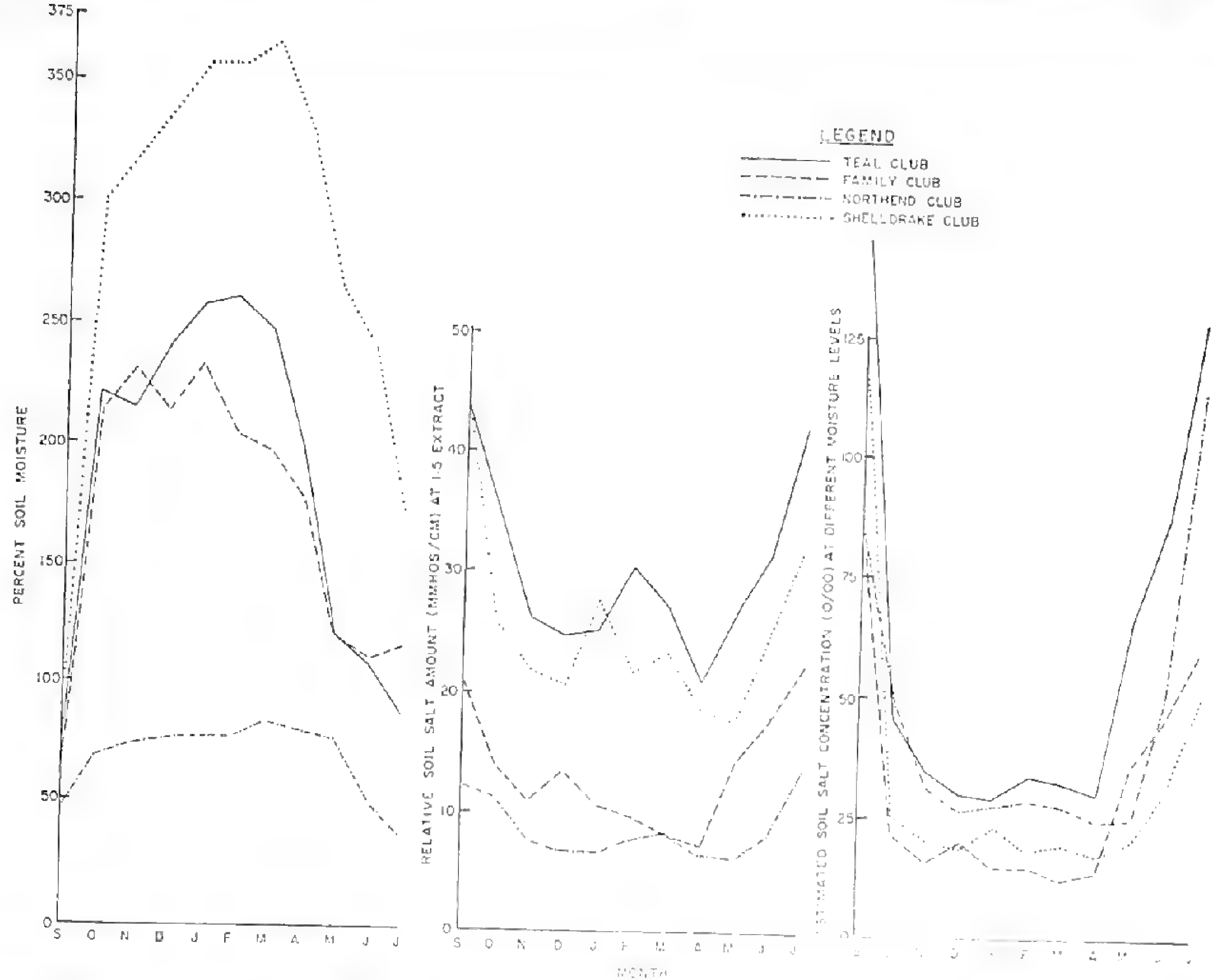


FIGURE 2. Monthly mean soil salinities and percent soil moistures occurring in the first foot of soil on individual duck clubs.

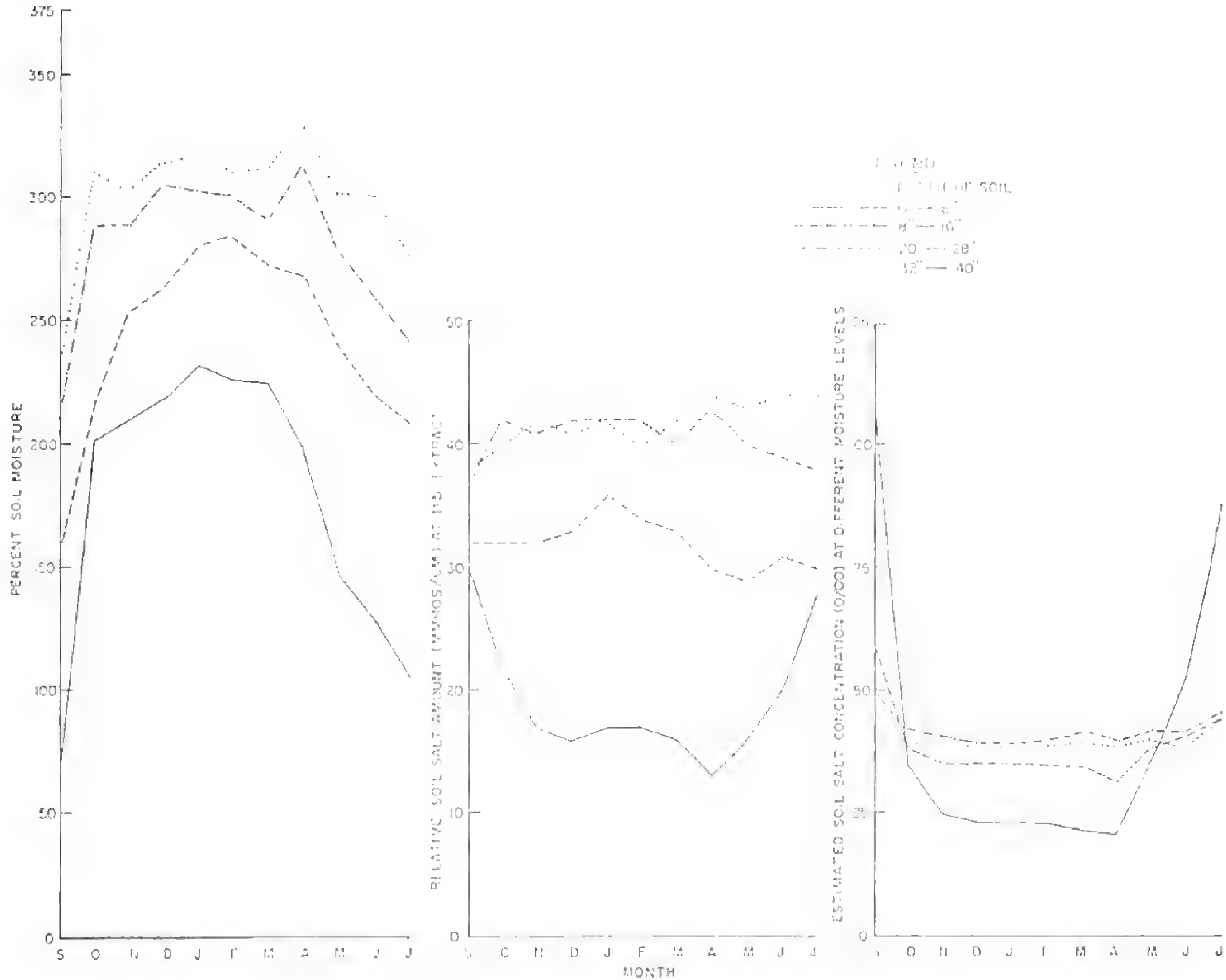


FIGURE 3. Monthly salinity and moisture conditions, average of four duck clubs.

at its lowest and the amount of salt was at its highest." Mall also determined that the salinities present in the second and third foot of soil were usually higher and much less variable than in the surface foot.

The application of channel water (freshened by USBR releases) with a 3½ month mean salinity of 1.8‰ resulted in a large reduction of the amount of salt and concentration of salt in the surface 8 inches of soil. Soil salt concentrations in the first 8 inches were reduced by 72–85% of the initial levels while the reductions in soil salt amounts ranged from 50–67% of the initial levels (Table 2). Approximately 84% of the reduction in salt concentration occurred during the first month of flooding although the ponds were flooded and water circulated from September until April (Figure 4). Obviously, a large part of the initial reduction was due to dilution rather than actual removal of salt, although 46% of the total reduction in soil salt amount also occurred during the first month.

The differences observed between clubs in the reduction of salt amount are attributable principally to: (i) soil permeability and (ii) drainage efficiency. The effects of draining can be seen by comparing the Teal and Family clubs (Table 3). Although both clubs have Joice type soils, draining accounted for 24% of the salt removed from the Family Club and only 16% from the Teal Club. The difference in draining efficiency is due to the location of the drainage ditches. Ditches on the Family Club were located closer together and therefore drained smaller areas. There were also smaller "bleeder" ditches on the Family Club which led from the center of the pond bottom to the peripheral, main ditches. Thus drainage was complete and uniform. The Teal Club, on the other hand, did not have these bleeder ditches and in the lower areas of the pond, water removal was accomplished as much by evaporation as by drainage.

TABLE 3. Duration of Flooding and Drainage on Individual Gun Clubs and the Resultant Reductions in Soil Salinity *

Club name	Months flooded and circulating	Months draining	Months dry	Percent of total reduction in relative soil salt amounts while: Flooded and circulating	Draining
Shelldrake	3.5	2.5	6	94	6
Teal	3.5	2.5	6	84	16
Family	3.5	2.5	6	76	24
Northend	5.0	2.0	5	97	3

* Table values represent only the 0–8 inch level.

As expected, the Northend Club with its dense clay soils had the lowest percentage reduction in salt amount overall and during draining. The Shelldrake Club had the greatest potential of reducing the salt load because of its porous soils, but this potential was not reached due mainly to the poor drainage system that existed at that time.

Virtually all reductions in soil salt concentrations occurred during the initial 2 months of flooding and circulating between mid-September to December (Figure 4). Soil salt concentration and amount then seemed to stabilize until spring draining commenced. A similar pattern of salinity reduction was observed by Mall (1969).

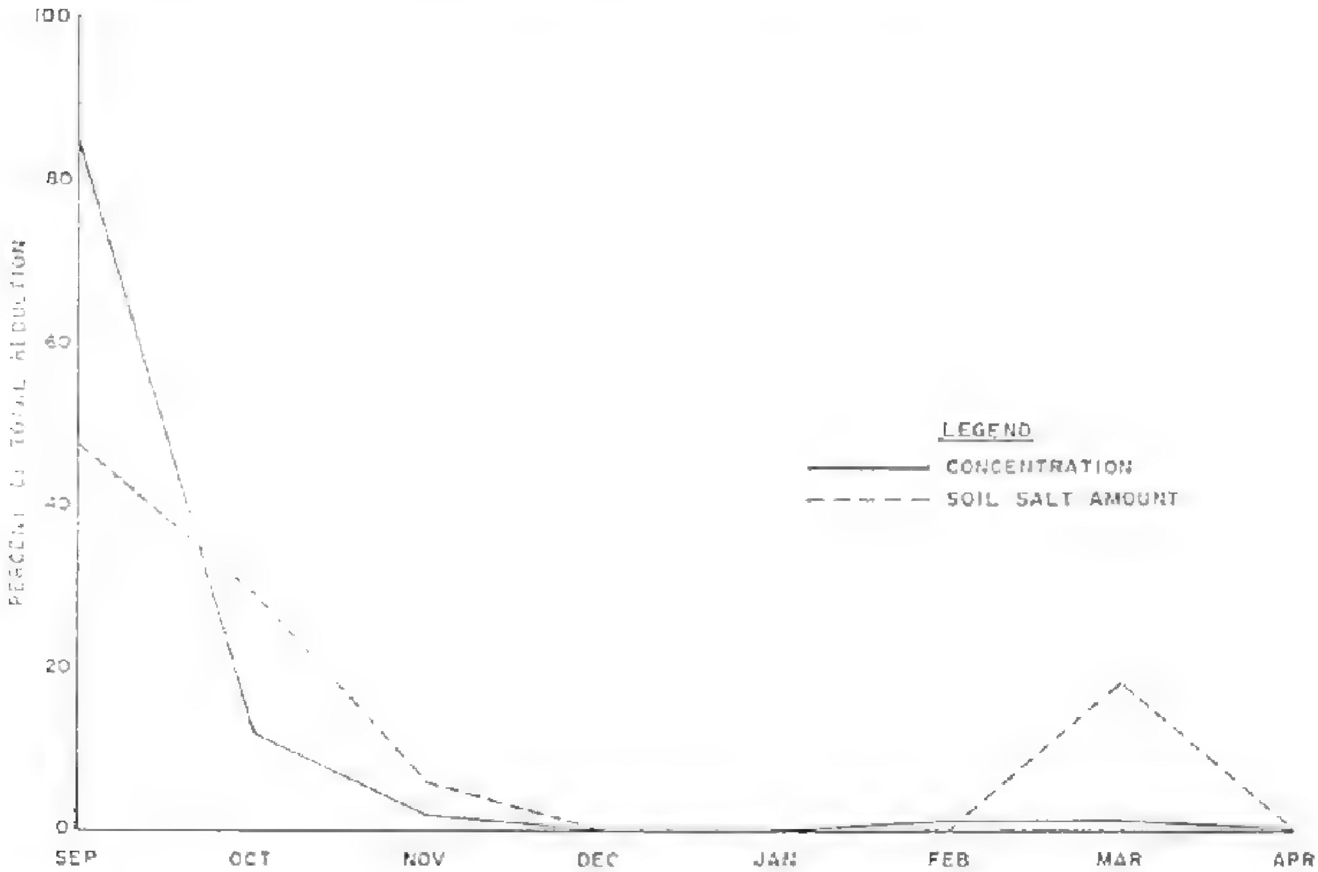


FIGURE 4. Percent of reduction in soil salt concentration and amount occurring in the 0 to 8-inch soil level, means of four duck clubs.

Conclusions

This study indicates the possibility of removing considerable amounts of salt from the soil profile by flooding with low salinity water of 3‰ or less (Figure 4). If further salt removal could be attained through leaching, a favorable salt balance for alkali bulrush production could occur in the profiles. Salt concentrations did not reflect the spring reductions in soil salt amounts. While drainage was removing salt, it was at the same time reducing the soil moisture, apparently at a proportional rate, thus maintaining a nearly constant salt concentration.

May is the critical month during which alkali bulrush seed heads are forming. According to Mall (1969), the soil salinity in the root zone should be between 9 and 14‰ for maximum seed production.

The data show that the soil salinities in the test ponds were not within the acceptable range of 9 to 14‰ in May, despite the fact that low salinity water (0.9 to 3.0‰) was used for flooding. Further, a comparison of soil samples collected from the clubs in July 1968 indicated that the summer soil salinities would continue to increase throughout August and September to either equal or exceed the levels present during the fall of 1967. Thus, if present water management practices are continued, there is a strong indication that future spring soil salinities on these clubs will continue to exceed those levels required for maximum seed production.

The application of relatively fresh water in the fall and its removal immediately following the waterfowl hunting season in January did not produce the 9 to 14‰ soil salt concentration in the month of May that is necessary for optimum alkali bulrush seed production. The attainment of this objective on a large scale throughout the Suisun Marsh is unlikely under prevailing water management practices.

Part II

HIGH SALINITY INFILTROMETER STUDY

This phase of the field study was initiated April 25, 1968. Its purpose was to determine the interrelationship between soil salts and the salinity of applied water. Emphasis was placed on observing the changes in soil salt amounts and concentrations resulting from the application of highly saline water, similar in quality to that predicted in the marsh environs at the 1990 level of development. The effects of applying relatively fresh water and controlled drainage on soil salinity were also studied.

Study Area

A small pond of approximately 7 acres in the northwest corner of Joice Island Refuge was selected as the study site (Figures 1 and 5). The test pond was completely isolated from the rest of the refuge by a high levee, and public access was limited.

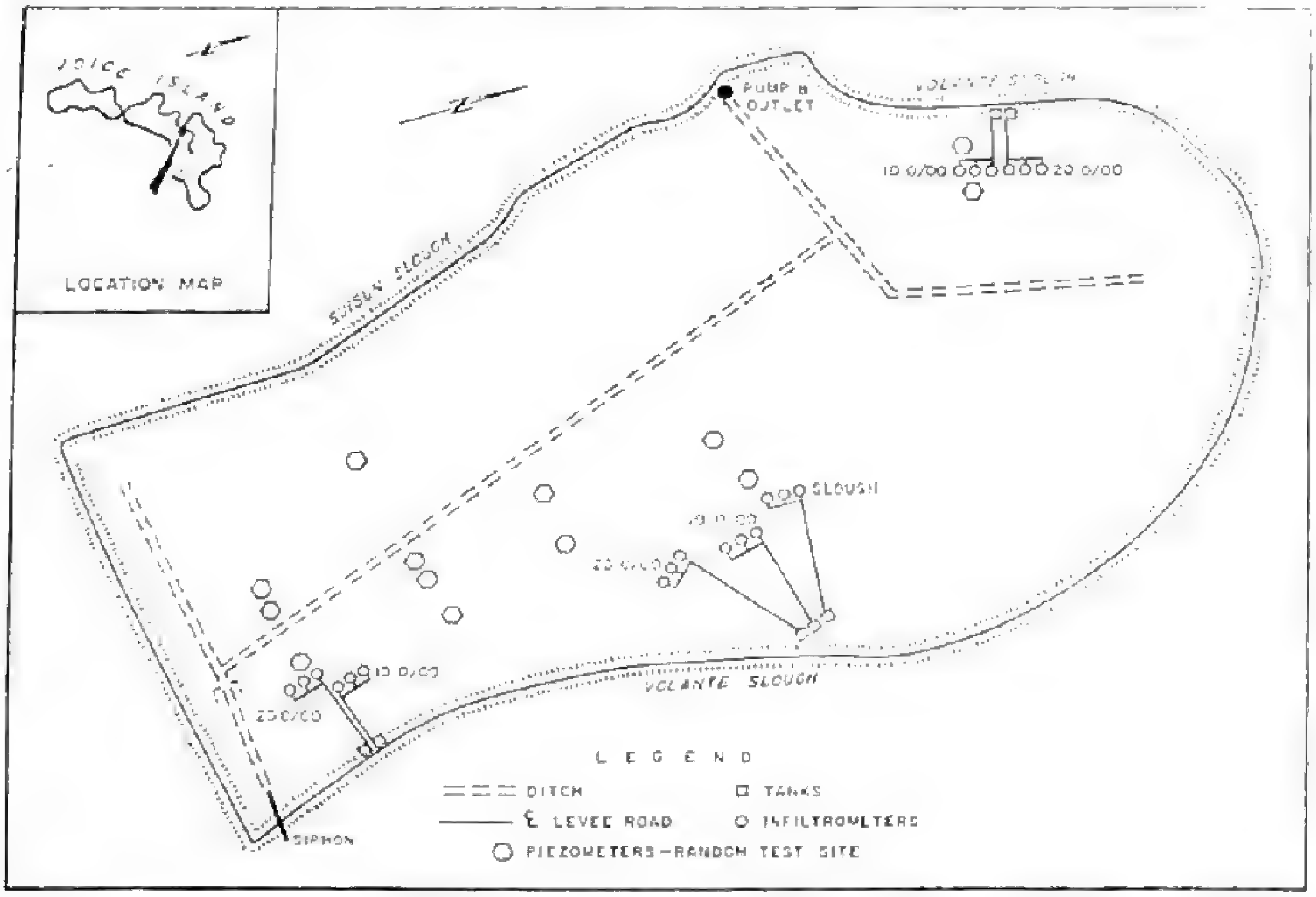


FIGURE 5. Suisun Marsh infiltrometer study pond.

Soils

The overall soil type of the study pond at the 0 to 8-inch level was Tamba. This was determined by calculating the mean percent soil moisture at saturation of 36 sampling sites. Again, as with the duck

club study, a positive relationship between the percent soil moisture at saturation and percent organic matter was assumed. The mean percent soil moisture at saturation in the study pond was 145%. The organic matter content relative to the duck club soils (Table 2) was 1.8.

Tamba soils consist of mottled gray clay and black muck. They are strongly acid and highly saline. Natural drainage is very poor and sub-soil permeability is moderate. Tamba soils constitute approximately 28% of Suisun Marsh soils.

Vegetation

The dominant plant in the study pond was saltgrass. Saltgrass covered approximately 30% of the pond in nearly pure stand and was associated with other marsh plants in all but one area. The only area exclusive of saltgrass was a pure stand of cat-tail (*Typha latifolia*). The stand of cat-tail was in the center of the pond adjacent to one of the drainage ditches and extended out into a low area in the pond. Cat-tail lined most of the other original ditches in the pond. Historically these ditches were always flooded and thus provided ideal growing conditions for cat-tail.

A large, dense stand of alkali bulrush occupied approximately 25% of the pond, extending from the edge of the cat-tail stand south along the center ditch to the road. Saltgrass was present throughout the alkali bulrush as a subdominant species.

Pickleweed (*Salicornia virginica*) was also found in association with saltgrass and was abundant on the western side of the pond.

Small pure stands of Olney bulrush and Baltic rush (*Juncus balticus*) were present in two locations at the northern end of the pond. These two plants, requiring relatively fresh soil conditions, probably indicated the presence of levee leaks. The levee and other more elevated areas of the pond supported grasses and annual herbs such as fat-hen and curly dock.

During the summer of 1968, a fire burned off the vegetation of a 2-acre area on the west side of the pond. Immediately following fall rains, this bare area was refoliated by brass buttons, pickleweed and miscellaneous upland herbs and grasses. Within a year after the burn however, pickleweed and saltgrass returned to dominance.

Water Control Facilities

Initially, the study pond had two main ditches. These ditches were overgrown and badly silted. The only water control device was a 3-ft square culvert located on the west side of the pond which ran through the levee and into Suisun Slough. The large wooden flapgate with which it was fitted was inoperable and was replaced.

Considerable effort was expended to improve and modify the water control facilities. This was necessary to meet the objectives of the study. Approximately 1,650 ft of existing ditch was cleaned and deepened, and 350 ft of new ditch was extended into the northeastern section of the pond. The new ditches averaged 4 ft deep, 9 ft wide at the top, and 4 ft wide at the bottom.

A siphon, 60 ft long and 8 inches in diameter, was constructed in the southeastern corner to provide circulation when the pond was flooded. Water was siphoned from Volante Slough over the levee and into the study pond (see Figure 5).

2—83935

The flapgate was replaced by a 36-inch Armco metal flapgate. A box weir with removable slats and an open top was installed on the inside end of the culvert and another 36-inch flapgate was attached to the weir. Thus, by opening or closing the flapgate, it was possible to flood or drain the study pond at will as long as the tides were favorable. The open-topped weir insured that the water level of the pond would not exceed the desired levels.

The elevation of the flapgates was inadequate to drain the pond. Therefore, an electric centrifugal pump with a capacity of 700 gal per min was mounted on a platform 4 ft above the levee next to the culvert. A 6-inch steel pipe fitted with a footvalve extended vertically downward from the pump to the ditch bottom. During draining, a float switch activated the pump periodically as the ditch refilled from the seeping water.

The ditch water was then conveyed across the levee and discharged into Suisun Slough through a 6-inch steel pipe.

A Stevens A-35 type stage recorder was placed in the ditch to record pond water levels.

In the spring of 1969 the continual and unpredictable clogging of the pump impellers by small fish and debris proved to be a major problem. A wire-mesh box was installed around the footvalve in an effort to screen out foreign materials but this was ineffective. Thus, continual maintenance of the pump was necessary and it was impossible to adhere to the preplanned water management schedule.

Methods and Sampling Procedures

Water Management Regime

The experimental management regime was established in accordance with presently accepted sound water management for the Suisun Marsh; namely, fall flooding, spring draining, and reflooding followed by water withdrawal. In the interest of time and economy, it was decided to condense the operational time scale of the program. To that end, 7-day intervals were designed to represent monthly intervals. Two complete cycles of flooding and draining under the condensed schedule were completed (Table 4).

When it became apparent that the high soil salinities observed under natural conditions were not being achieved under the condensed time cycle concept, a third test was undertaken in which the water management program was implemented on the normal chronological basis.

Sampling Procedures and Data Reduction—Test Cycle I

Test Cycle I was initiated on April 25, 1968 and ended July 25, 1968. Field sampling methods were designed to provide data on four variables: soil salt concentrations, soil salt amounts, soil moisture, and the salinity of applied water.

A grid pattern of 13 piezometer stations was established throughout the study pond (Figure 5). The information collected at these stations provided a basis for comparing normal soil salinity changes occurring throughout the pond with those taking place within the infiltrometers at the test sites.

Each piezometer consisted of a length of $\frac{3}{4}$ inch A.V.C. plastic pipe capped at the bottom. A network of $\frac{1}{4}$ inch holes was drilled in the

TABLE 4. **Infiltrometer Water Management Schedules for Test Cycles I and II**

Test Cycle I

Schematic time	Week	Real time	Activity
October	1	5/3 – 5/9	Pond flooded and circulating
November	2	5/10 – 5/16	Pond flooded and circulating
December	3	5/17 – 5/23	Pond flooded and circulating
January	4	5/24 – 5/30	Pond flooded and circulating
February	5	5/31 – 6/6*	Pond drained
March	6	6/7 – 6/13	Pond flooded and circulating
April	7	6/14 – 6/20	Pond flooded
May	8	6/21 – 6/27	Pond flooded
June	9	6/28 – 7/4	Pond drained
July	10	7/5 – 7/11	Pond dry
August	11	7/12 – 7/19	Pond dry
September	12	7/20 – 7/25	Pond dry

Test Cycle II

Schematic time	Week	Real time	Activity
October	1	7/26 – 8/1	Pond flooding initiated 7/26
November	2	8/2 – 8/8	Pond flooded and circulating
December	3	8/9 – 8/15	Pond flooded and circulating
January	4	8/16 – 8/22	Pond flooded and circulating
February	5	8/23 – 8/29	Pond drained
March	6	8/30 – 9/5	Pond flooded and circulating
April	7	9/6 – 9/12	Pond flooded and circulating
May	8	9/13 – 9/20	Pond flooded and circulating
June	9	9/20 – 9/26	Pond drained
July	10	9/27 – 10/3	Pond dry
August	11	10/4 – 10/10	Pond dry
September	12	10/11 – 10/19	Pond dry
None	--	10/19 –	Pond reflooded and on real-time basis

* Draining and/or refilling operations were normally initated at end of prior day's soil sampling efforts.

pipe extending from the cap to 12 inches above the cap. Three piezometers were placed 12 inches apart at each station and driven into the ground at depth increments of 1 ft. Thus the ground water collected in each tube represented the soil salt concentration at a specific site and depth.

Sampling of the piezometers which was done weekly, consisted of first evacuating the water from the tubes with a small, hand-operated bilge pump. After the piezometer had refilled with ground water, the cell of a portable solu-bridge was lowered into the tube and the conductivity in micromhos ($EC_{25} \times 10^{-6}$) was read directly from the instrument.

The soil moisture at each test site was determined gravimetrically from a soil sample removed by a hand auger from the first, second and third foot. It was possible to sample only 8 inches of soil at each depth increment due to the length of the auger bit. For simplification the soil moisture calculated for the 8-inch core sample was used to represent the soil moisture for the entire foot. The procedures for calculation of soil moisture and salinity were the same as those previously described in the duck club phase of this study.

Surface water was collected at each station in 4-oz bottles and the salinity of each determined in the laboratory with a Model RC 16B2 conductivity bridge. All conductivity measurements were corrected to a standard temperature of 25 C ($EC_{25} \times 10^{-3}$).

Test Sites. Testing sites were established at three locations on the pond (Figure 5). Soil plots were isolated from the surrounding pond by driving 3-ft by 3-ft open-ended steel cylinders called infiltrometers 6 inches into the ground. Two piezometers were driven into the soil near the center of each infiltrometer to sample the soil water at the first and the second foot.

Each test site consisted of six infiltrometers supplied with saline water from two 330 gal reservoir tanks. Each tank supplied water via plastic pipe and tubing to three infiltrometers. One reservoir contained water having 20‰ total dissolved solids; the other 10‰ water. This provided nine replicates of each salinity.

In addition, another set of three infiltrometers was supplied with water from adjacent Volante Slough to serve as an infiltrometer control. The natural pond surrounding the infiltrometer received water from both Volante Slough and Suisun Slough.

The experimental water management scheme of the 21 infiltrometers followed the same flooding and drainage schedule as the main pond. The infiltrometers were filled at the same time and rate from their respective reservoirs as was the surrounding pond to maintain equal head pressure around the infiltrometers. Evaporative loss from inside the infiltrometers was compensated for by allowing a small, constant flow of test water to drip into them. Despite conscientious efforts to maintain equal water levels between the pond and the infiltrometers after flooding, the level inside the cylinders often exceeded the level outside.

The methods used to sample the test plots were identical to those described for the main pond.

Sampling Procedures and Data Reduction—Test Cycle II

Test Cycle II began July 26, 1968 and ended October 18, 1968. Sampling procedures and data reduction methods were identical to those described for Test Cycle I. Following the termination of Test Cycle II high salinity water was again applied to the test sites. This "post Test Cycle II flooding" was initiated to raise the soil salinity levels in preparation for Test Cycle III.

Evaluation of Test Cycles I and II

The first phase of this investigation, performed on private gun clubs, established the cyclic nature of marsh soil-salt movements. The highest soil-salt concentrations during the year occurred in September and were the result of several months of drying. Test cycles I and II, which were operated on a condensed time scale, were useful in establishing some basic relationships between the quality of applied water and soil salts. These test cycles failed, however, to accurately simulate late summer conditions. The 4 weeks of drying allotted by the abbreviated schedule were insufficient to produce the extremely high salt concentrations witnessed on the gun clubs.

Sampling Procedures and Data Reduction—Test Cycle III

Test Cycle III was initiated in April of 1969. It was intended to allow the soil in the test plots to dry completely to achieve the extreme salinity levels observed on the private gun clubs, then measure the response to applications of 10 and 20‰ water. Unfortunately pump malfunctions and the development of levee leaks prevented pond drainage, so this test was terminated in November 1969.

Based on the earlier tests it was suspected that the repeated removal of soil cores from within the infiltrometers for analysis might change the normal rate of percolation. Therefore, at the conclusion of Test Cycle II in October 1968, during the post Test Cycle II flooding period, a Model P19 Nuclear Chicago neutron probe was used to determine the soil moisture at sampling sites for subsequent tests. Soil moistures determined by this method are expressed as "inches of water per cubic foot of soil." The percent moisture obtained through the neutron probe was used in the theoretical calculation of the relative amounts of soil salts as soil moisture depletion occurred.

Supplemental Test Pond

To obtain information regarding the ability of 20‰ water to suppress soil salinity in the late summer, highly saline soils, a supplemental testing program was initiated September 18, 1969. A test site consisting of three infiltrometers fed by one reservoir of 20‰ water was established in Pond C of the Joice Island Waterfowl Refuge (Figure 5). Two piezometers and one neutron probe tube were installed in each infiltrometer. A sampling station consisting of two piezometers and one neutron probe tube was also established adjacent to the infiltrometers in the main pond to serve as a control.

Pretest sampling in the dry pond bottom indicated that the soils there were highly saline and similar in type to those of the original test pond.

The infiltrometers were filled with 20‰ water at the same time and approximate rate as the rest of the pond was filled.

Samples of soil moisture, soil salt concentration and surface water were taken weekly. Sampling techniques and data reduction procedures were identical to those described for Test Cycle III. Testing was terminated on December 24, 1969.

Results and Discussion

General

Analysis of the data obtained from this study demonstrated a statistically significant relationship between the quality of applied water and the resulting salt concentrations in the first foot of soil.

The calculated correlation coefficient indicated a significant relationship between the soil salt concentration in the first foot of soil and the salinity of water applied on plots located outside the infiltrometers ($r = 0.258$; $r_{0.95} = 0.237$, $N = 77$).

Correlation analysis further indicated a highly significant relationship between the salinity of applied water and the resulting soil salt concentration in those soils isolated by the infiltrometers. This relationship was significant in both the 0 to 12-inch level ($r = 0.637$; $r_{0.99} = 0.277$, $N = 84$) and the 12 to 24-inch level ($r = 0.488$; $r_{0.99} = 0.277$, $N = 84$).

20‰ Infiltrometers

Test Cycle I (condensed schedule). During the simulated fall and spring flooding of Test Cycle I, applied water at the surface inside the infiltrometers ranged from 15.4‰ to 21.2‰ with an 8-week mean of 18.8‰. Throughout the flooded periods, soil salt concentration fluctuated directly with changes in the salinity of applied test water, particulary in the first foot (Figure 6). The soil salt concentrations and amounts in the first and second foot increased following the simulated spring flooding of Test Cycle I (Figure 6).

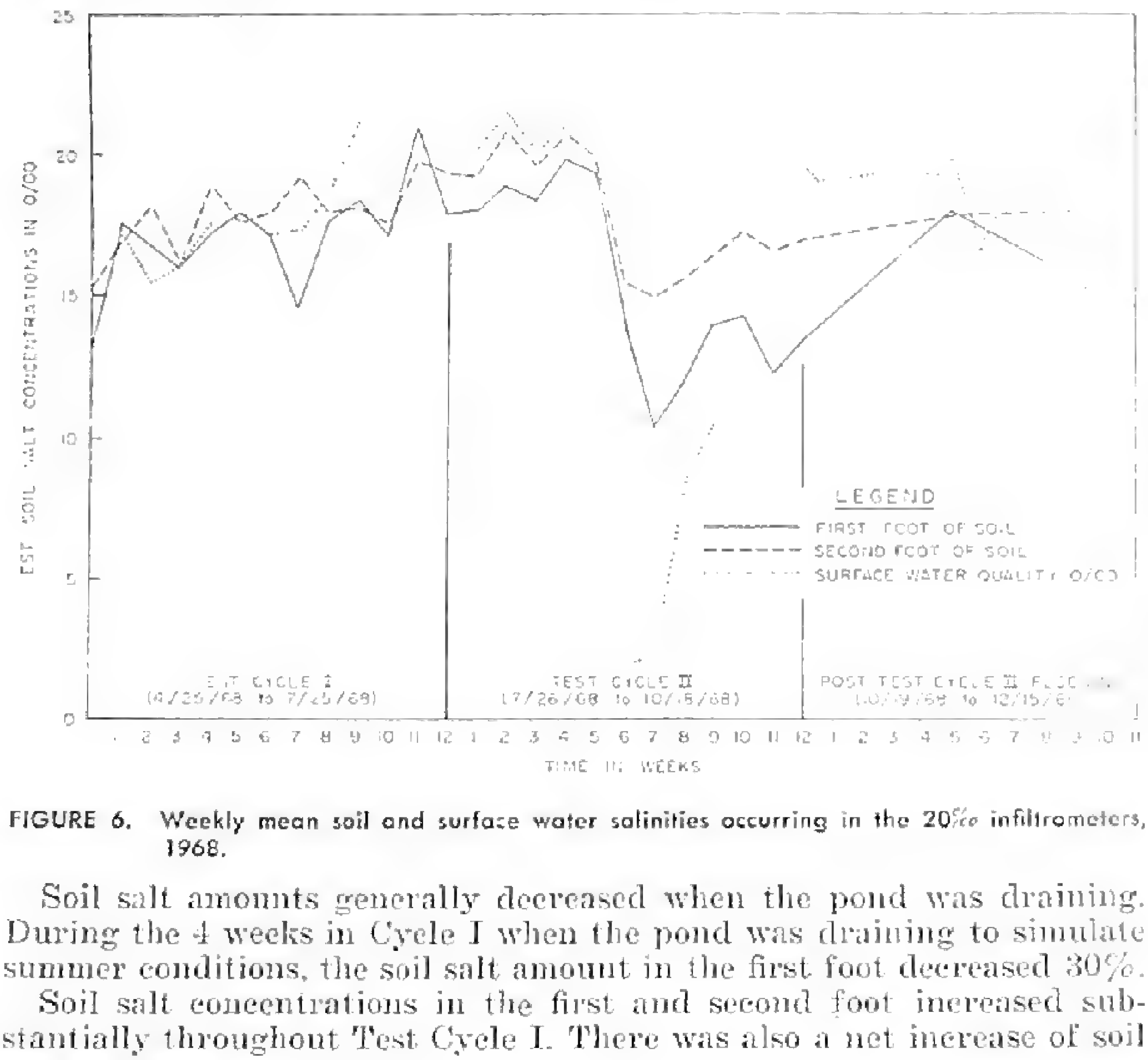


FIGURE 6. Weekly mean soil and surface water salinities occurring in the 20‰ infiltrometers, 1968.

Soil salt amounts generally decreased when the pond was draining. During the 4 weeks in Cycle I when the pond was draining to simulate summer conditions, the soil salt amount in the first foot decreased 30%.

Soil salt concentrations in the first and second foot increased substantially throughout Test Cycle I. There was also a net increase of soil salt amounts.

Test Cycle II (condensed schedule). During the simulated fall flooding of Test Cycle II, the surface water sampled from inside the infiltrometers ranged from 20.0‰ to 21.4‰ with a 4-week mean of 20.5‰ (Figure 6). During this period of flooding, the salt concentrations in the first and second foot varied directly with the quality of the surface water and were almost equal to it.

The amount of salt in the first and second foot increased in response to the application of the saline water.

The combined effect, in Cycle II, of draining for 1 week and then flooding with relatively fresh water (3‰) for 2 weeks to simulate actual spring conditions resulted in substantial decreases in soil salt

concentrations and amounts in the first and second foot (Figure 6).

Following the 2-week application of relatively fresh water, the salinity of surface water was purposely increased to 8.3‰. At this point soil salt concentrations and amounts began rising again. Four weeks of drainage simulating summer conditions caused minor reductions in salt amounts and concentrations.

Correlation analysis established that the increases in salt concentrations and amounts occurring from the start of Test Cycle I to the fourth week of Test Cycle II were significant in the first and second foot at the 95% level of confidence.

Upon completion of Cycle II, high salinity water was again applied to the infiltrometers (post Test Cycle II flooding period). The quality of water applied ranged from 15 to 19.5‰ for 2½ months and resulted in immediate and rapid increases in both salt amounts and concentrations (Figure 6). Sampling ceased on December 15, 1968.

Test Cycle III (real time). The infiltrometers were flooded during the first 5 weeks of Test Cycle III. The salinity of surface water inside the cylinders ranged from 17–24‰ and had a 5-week mean of 21‰. A very close relationship existed between soil salt levels in the first and second foot and the salinity of the surface water. Samples collected during the last week of initial flooding showed that the soil salt concentrations and water quality differed by only 1‰ (Figure 7). Soil salt concentrations and amounts in the first and second foot peaked in the fifth week of flooding.

Following the 5 weeks of flooding with high salinity water, the pond was drained for 2 weeks and then reflooded with low salinity water

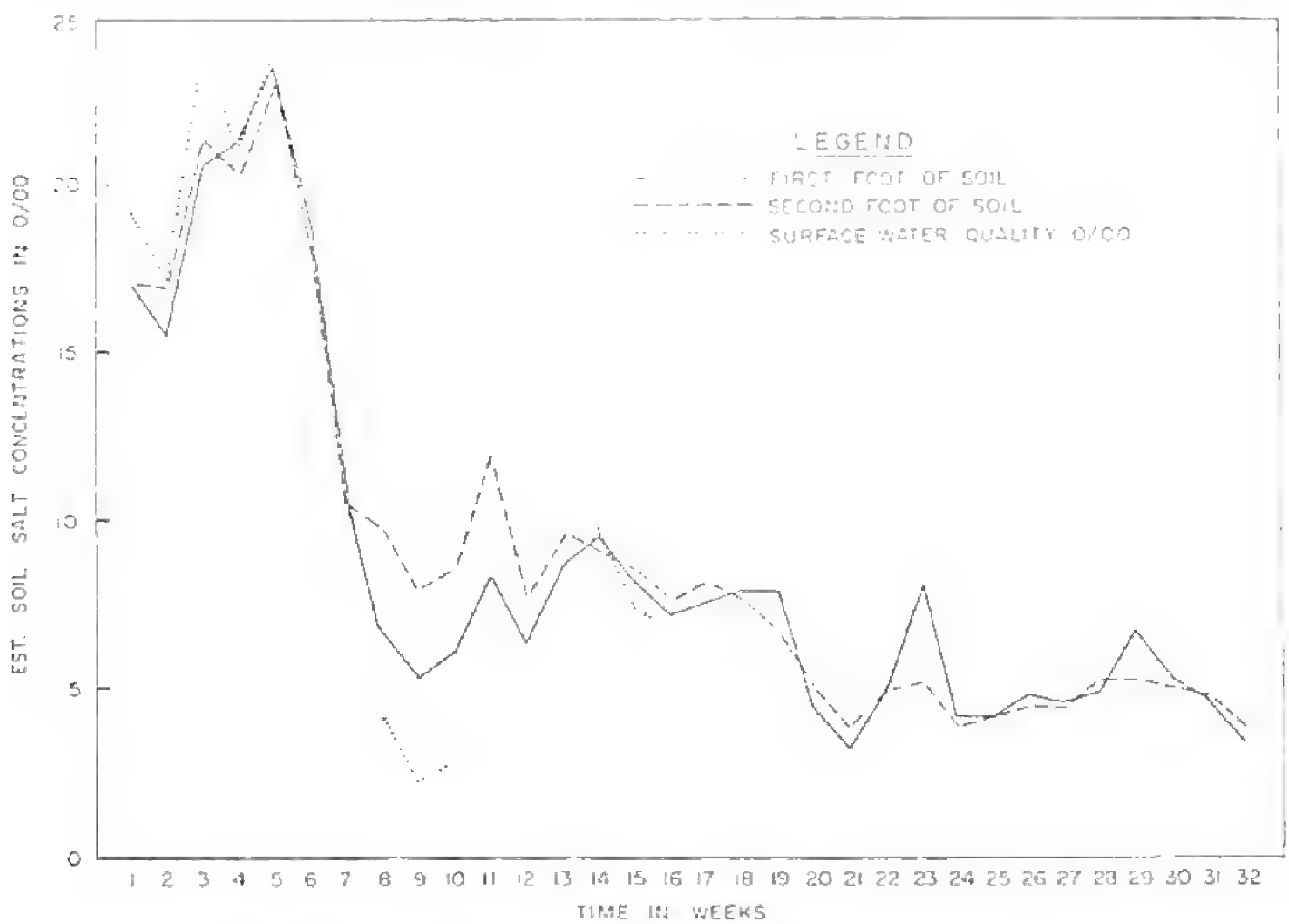


FIGURE 7. Weekly mean soil and surface water salinities occurring in the 20‰ infiltrometers, 1969.

for 3 weeks. The salinity of surface water during this second period of flooding ranged from 2.3–4.1‰ and averaged 3‰. The combination of drainage for 2 weeks and reflooding with relatively fresh water for 3 weeks, resulted in substantial reductions in salt levels.

The salt reductions occurring during this 5-week period are attributed to drainage and flooding. It is important that drainage was accomplished very rapidly. All water control facilities were functioning efficiently so that most of the surface water was removed in 1 week.

The study schedule demanded that immediately following the 3-week application of low salinity water that the pond be drained for 3 consecutive months in the summer to simulate actual duck club conditions. After only 4 weeks of drying time, during which soil salt levels generally increased, exceptionally high tides overtopped the study area levees and inundated the pond. Pump malfunctions prevented drainage for 3 weeks.

Drainage was in progress for 2 weeks when a second unscheduled flood occurred. Another week passed before the simulated summer drainage was begun again. After 2 weeks of drainage a substantial reduction occurred in soil salt levels. Frequent pump malfunctions and unscheduled flooding prevented the accurate representation of summer conditions. Testing was terminated in November 1969.

10 ‰ Infiltrometers

Test Cycle I (condensed schedule). During the simulated fall and spring flooding of Test Cycle I, the surface water inside the infiltrometer ranged from 10.0‰ to 16.1‰ with an 8-week mean of 13.3‰ (Figure 8). Throughout these periods of flooding, the soil salt concentrations varied directly with changes in the salinity of applied water. Soil salt concentrations and amounts in the second foot sometimes responded inversely; reductions in the first foot in several instances were paralleled by increases in the second foot. Soil salts apparently were being leached out of the surface soils and deposited in lower levels.

The general trend in salt movements throughout this period was nearly constant. The soil salt concentrations that existed before the tests began differed only slightly from the quality of the applied water, which probably accounts for the relative stability of salt levels during the test.

Minor reductions in soil salt amounts were associated with periods of drainage in the first foot. A 26% reduction in salt amounts occurred in the second foot during the 4 weeks of drainage which were intended to represent summer conditions. This reduction was the result of leaching.

Test Cycle II (condensed schedule). During the simulated fall flooding Test Cycle II, the surface water inside the infiltrometers ranged from 11.5‰ to 12.6‰ with a 4-week mean of 12.0‰. During this period, the salt concentrations in the first foot decreased from the level attained during the simulated summer conditions of Test Cycle I and were nearly equal to the salinity of the surface water (Figure 8). Soil salt amounts in the first foot stabilized.

The combined effect of draining for 1 week and reflooding with relatively fresh water (2.6‰) for 2 weeks (to simulate spring condi-

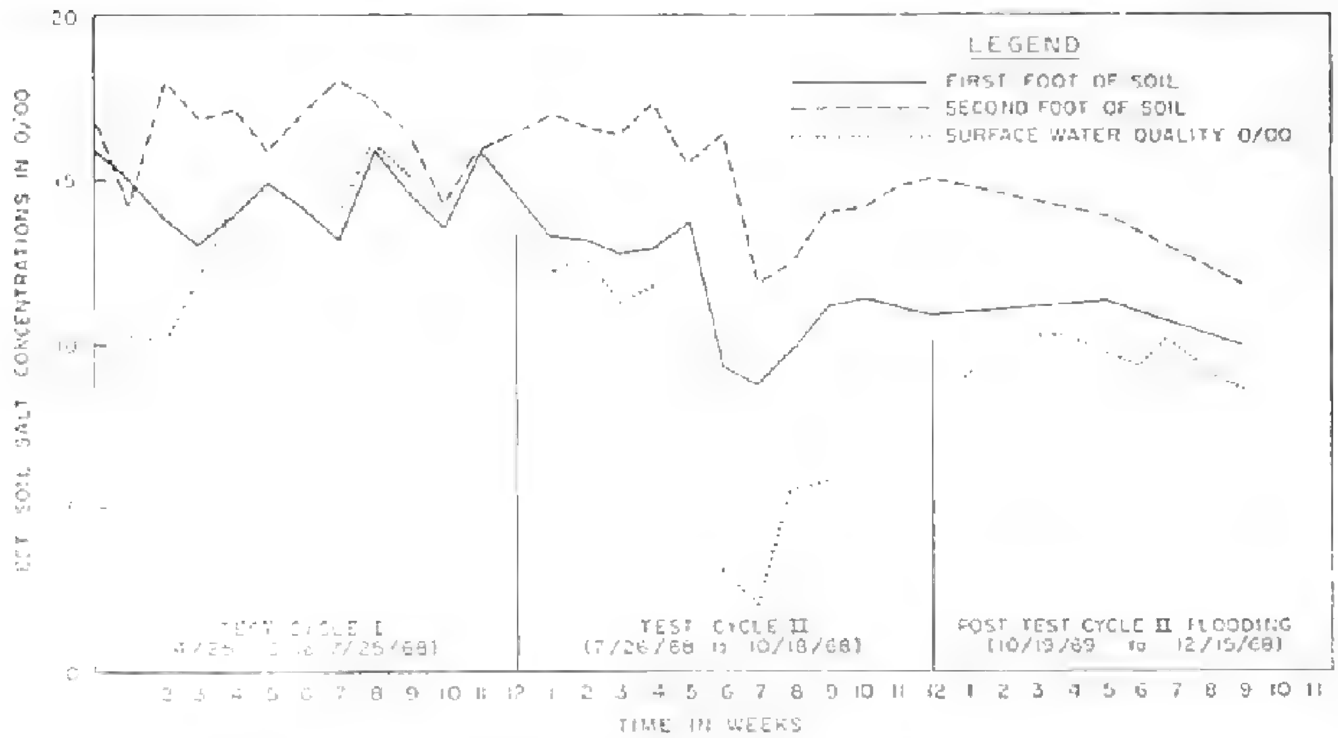


FIGURE 8. Weekly mean soil and surface water salinities occurring in the 10‰ infiltrometers, 1968.

tions), resulted in substantial decreases in soil salt concentrations and amounts in both the first and second foot of soil.

Following the 2-week application of relatively fresh water, the salinity of surface water was increased to about 6‰. At this point, soil salt concentrations and amounts began gradually increasing. Four weeks of drainage to simulate summer conditions produced only a slight increase in the salt level.

Upon completion of Cycle II, water ranging from 8.7 to 10.3‰ was applied to the sites. Only slight changes were noted in the salt levels in the first foot. A gradual decrease in soil salt amounts in the second foot of soil totalled 18% (Figure 8).

Test Cycle III (real time). During the first 5 weeks of Test Cycle III, the surface water in these infiltrometers ranged from 9.7‰ to 12.4‰ and averaged about 11‰. A very close relationship existed between the soil salt concentration in the first and second foot and the salinity of the surface water (Figure 9).

Drainage commenced in the sixth week of the test and continued for 2 weeks, followed by 3 weeks of flooding. The salinity of the surface water in the cylinder during this second period of flooding averaged 2.7‰. The combination of draining and reflooding resulted in substantial reductions of soil salt levels.

Following 3 weeks' application of low salinity water, summer drainage started. As described in the preceding sections, two unscheduled periods of flooding occurred shortly thereafter. Two weeks of drainage following the second unscheduled flooding resulted in large reductions of soil salts.

Infiltrometers Receiving Slough Water

Test Cycle I (condensed schedule). Surface water salinities in the infiltrometers supplied with slough water ranged from 4.4‰ to 13.2‰ with a mean for the test period of 8.9‰. Soil salt concentrations in the

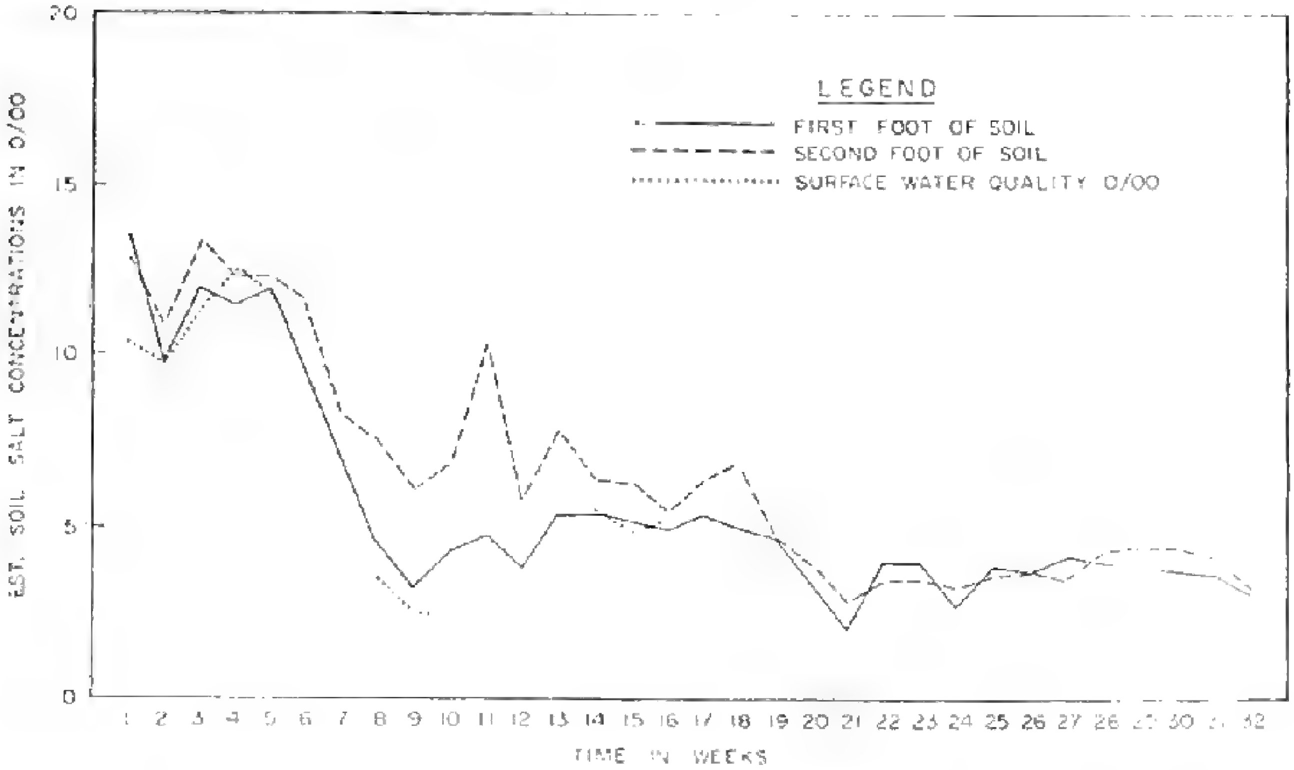


FIGURE 9. Weekly mean soil and surface water salinities occurring in the 10‰ infiltrometers during Test Cycle III, 1969.

first foot during the Test Cycle I ranged from 16.0‰ to 9.7‰ (Figure 10). A 41% reduction in the salt concentration occurred in the first foot during the first 10 weeks of this cycle. Three weeks of simulated summer conditions at the end of Cycle I reversed this downward trend and increased the salt concentration in the first foot. Soil salt amounts

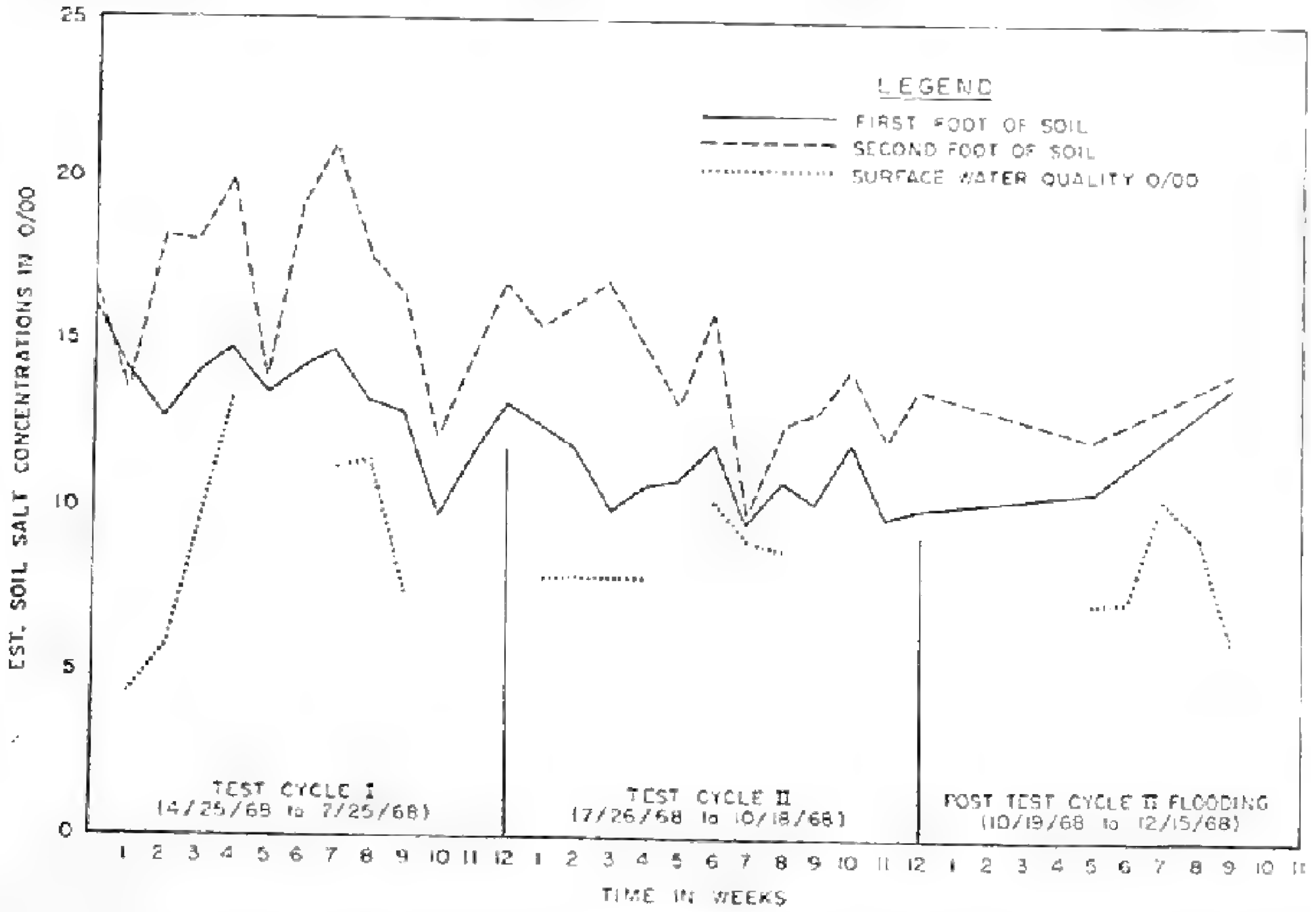


FIGURE 10. Weekly mean soil and surface water salinities occurring in the infiltrometers which received slough water during 1968.

varied widely through the test period, but were only slightly lower at the end of testing than at the start.

The salt levels in the second foot of soil varied greatly. This variation may be attributed, in part, to sampling error and to the fact that this test site consisted of only three replicates; the other test sites had nine replicates.

Generally speaking, salt levels in both the first and second foot of soil decreased sharply during the first week of drainage (due to leaching) and then immediately began to increase.

Test Cycle II (condensed schedule). Surface water salinities ranged from 7.8‰ to 10.1‰ with a mean of 8.4‰. Soil salt concentrations in the first foot during Test Cycle II ranged from 9.5‰ to 12.4‰ with a 12-week mean of 10.4‰ (Figure 10). The soil salt concentrations remained nearly constant after an initial reduction produced by reflooding the test sites following the simulated summer conditions of Test Cycle I.

Salt levels in the second foot again varied widely as in Test Cycle I. Small sample size and error are probable reasons for these fluctuations. Salt levels in both the first and second foot decreased during flooded periods and increased following drainage.

Test Cycle III (real time). Fluctuations in soil salt levels appeared to be closely related to the salinity of applied water (Figure 11). As soil moisture depletion occurred, soil salinity increased until the second period of flooding. The following 3 weeks of drainage resulted in large reductions of soil salinity levels at the first foot depth. A similar reduction occurred in the second foot although at a lesser magnitude. Because of unscheduled flooding and pump malfunctions, sampling was terminated in September.

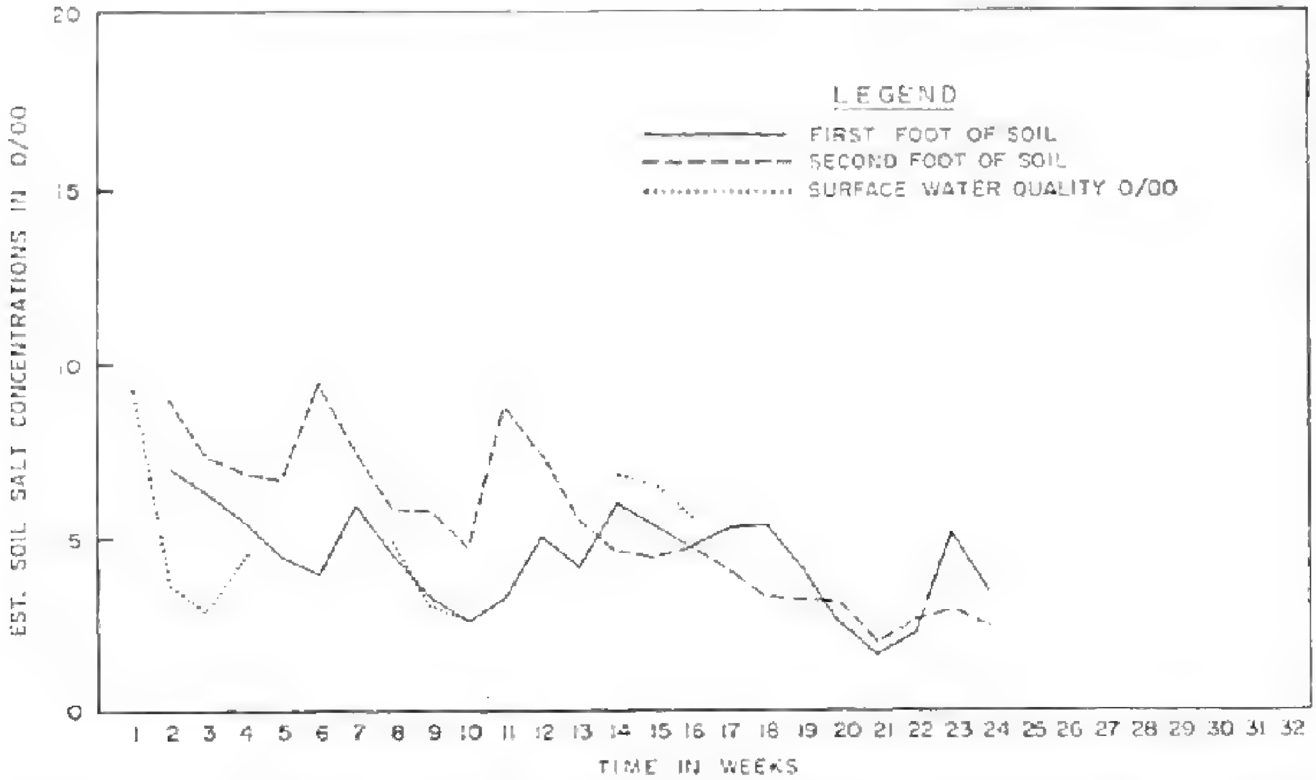


FIGURE 11. Weekly mean soil and surface water salinities occurring in the infiltrometers which received slough water during Test Cycle III, 1969.

Natural Pond Sites

Test Cycle I (condensed schedule). The most notable result of this study was the presence of three distinct levels of salinity. The soil salt amounts and concentrations increased with depth and no overlapping occurred. This same type of differentiation was observed during the investigation of the duck clubs.

The soil salt concentrations in the first foot varied throughout the test cycle; from a minimum of 10.7‰ to a maximum of 14.2‰ (Figure 12). Even less variance occurred in soil salt amounts in the first foot.

Fluctuations in soil salt levels were more pronounced in the second and third foot. The reason for this greater variability is not known.

For the most part, the soil salt levels increased during periods of drainage and then decreased when water was reapplied. A substantial increase in salt concentration occurred in the first foot during the simulated summer drying period in the last 3 weeks of the test cycle.

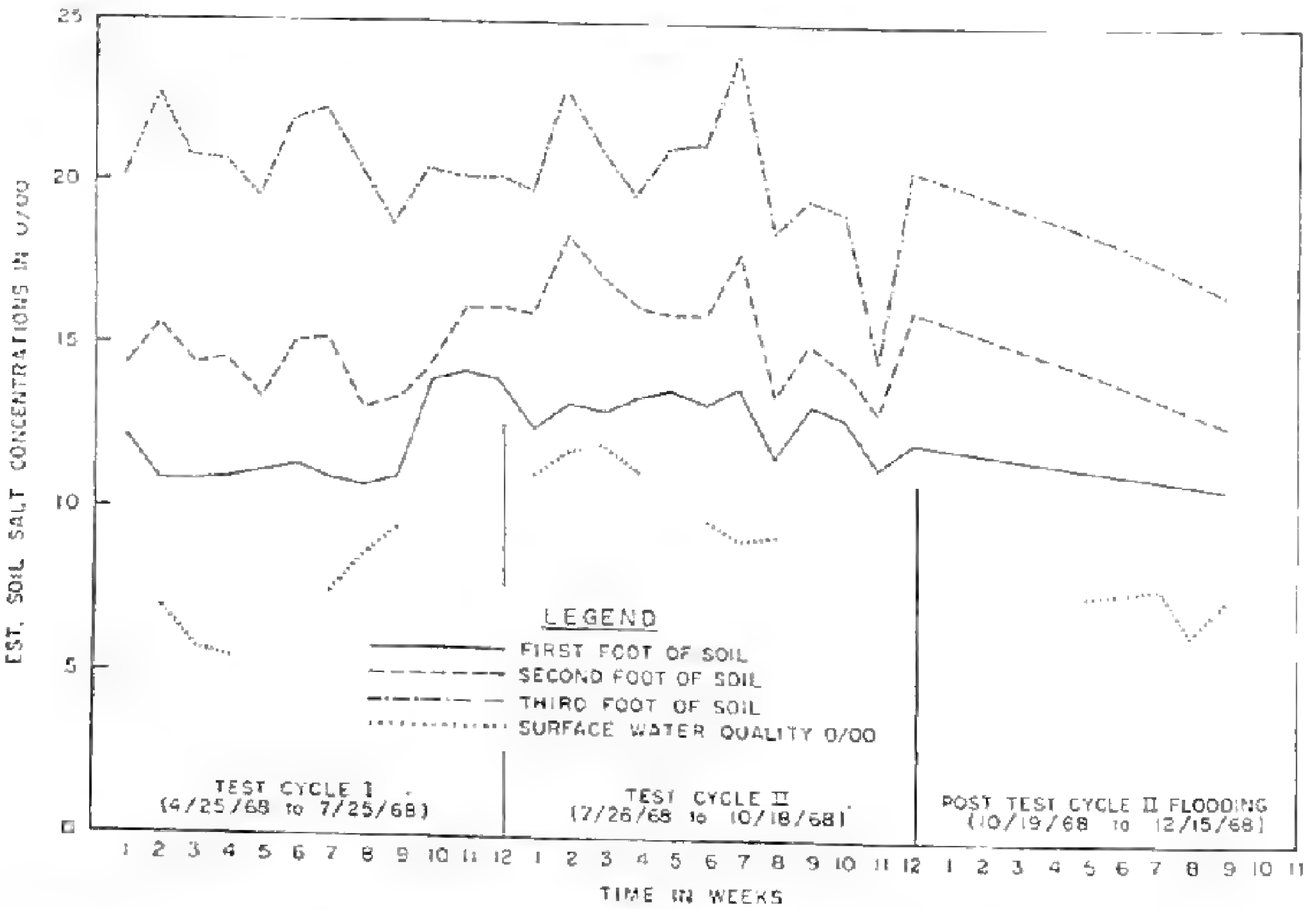


FIGURE 12. Weekly mean soil and surface water salinities occurring throughout the natural pond in 1968.

Test Cycle II (condensed schedule). The three distinct levels of salinity observed in Test Cycle I were maintained throughout Test Cycle II. Soil salt concentrations and amounts increased with depth (Figure 12). The magnitude of weekly variations also increased with depth. A decrease in both soil salt concentrations and amounts occurred during the middle of the simulated summer drawdown in Test Cycle II. This reduction in soil salts was noted in all three sampling levels.

Changes in soil salt concentrations and amounts followed basically the same cyclic curve described by the salinity of applied water. The salinity of surface water began at about 6‰, increased to 21‰, and then descended to about 7‰ at the conclusion of the study period. The

salt concentration in the first foot began at 12.2‰, increased to 14.2‰, and then descended to 12.2‰ at the end of the test cycle.

The cyclic variations in the salinity of water applied to the natural pond sites reflected the seasonal fluctuations of the adjacent natural channel salinities.

Test Cycle III (real time). Sampling results again established the existence of three distinct levels of salinity (Figure 13). Soil salt levels increased with depth. Fluctuations in soil salt levels were pronounced in the second and third foot.

Repeated flooding and drainage of the study pond during Test Cycle III resulted in soil salinity reductions exceeding 50% in all depths. Testing was terminated in November 1969.

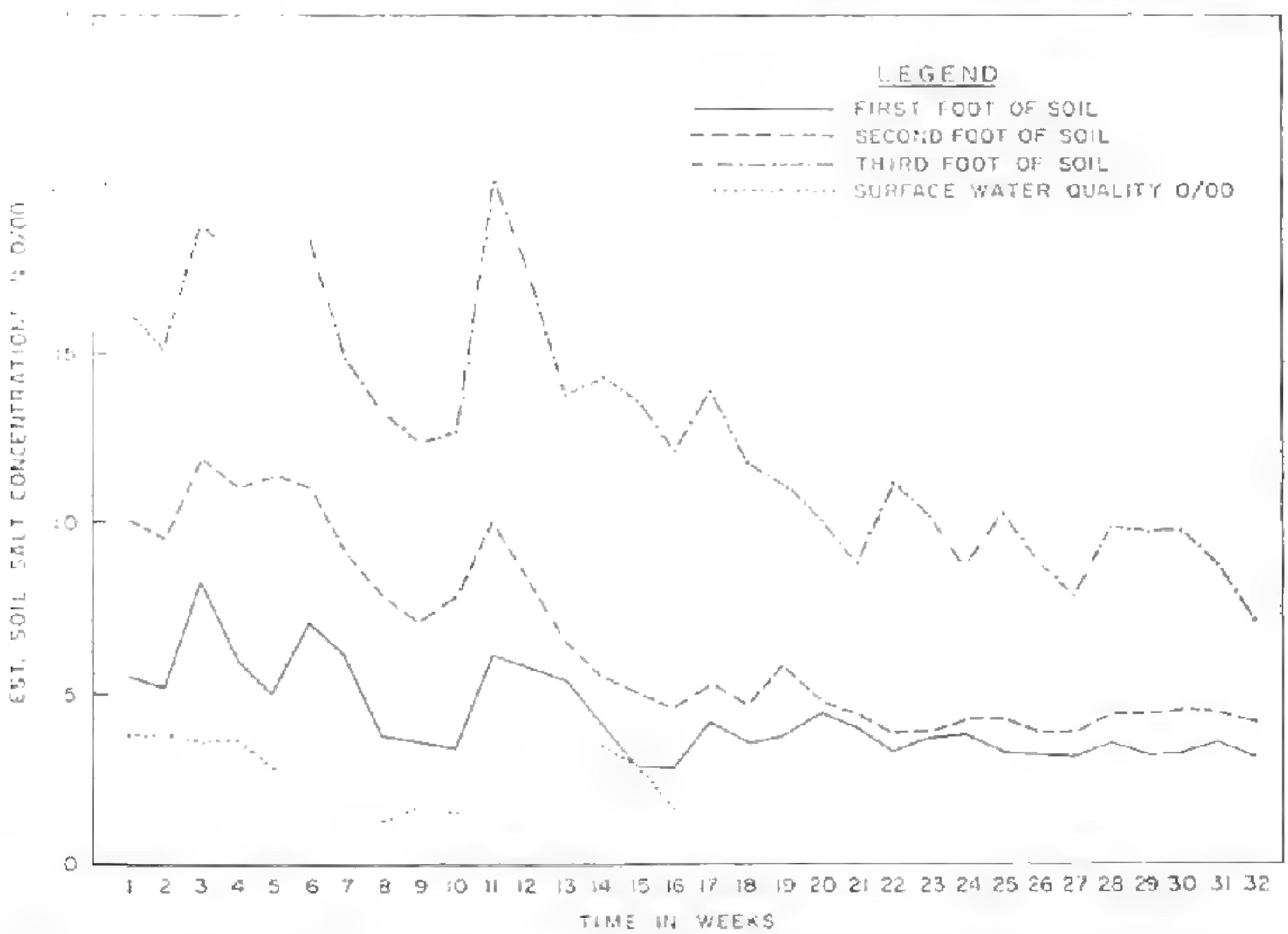


FIGURE 13. Weekly mean soil and surface water salinities occurring throughout the natural pond during Test Cycle III, 1969.

Supplemental Test Pond

20‰ Infiltrometers. The application of highly saline water to dry marsh soils resulted in large reductions in soil salt concentrations and amounts (Figure 14). The salinity of surface water sampled from inside the infiltrometers during the first 2 weeks of this test was 30‰. The soil salt concentrations and amounts in the first and second foot drastically decreased as a result of 2 weeks of flooding.

Soil salt levels stabilized after the second week of flooding and were nearly constant for the remaining 10 weeks of the test. The gradual freshening of surface water from 30‰ in the first week to a low in the eleventh week of 4% had no apparent effect upon soil salt concentrations or amounts in either the first or second foot. This is probably because no attempt was made to drain and leach this site.

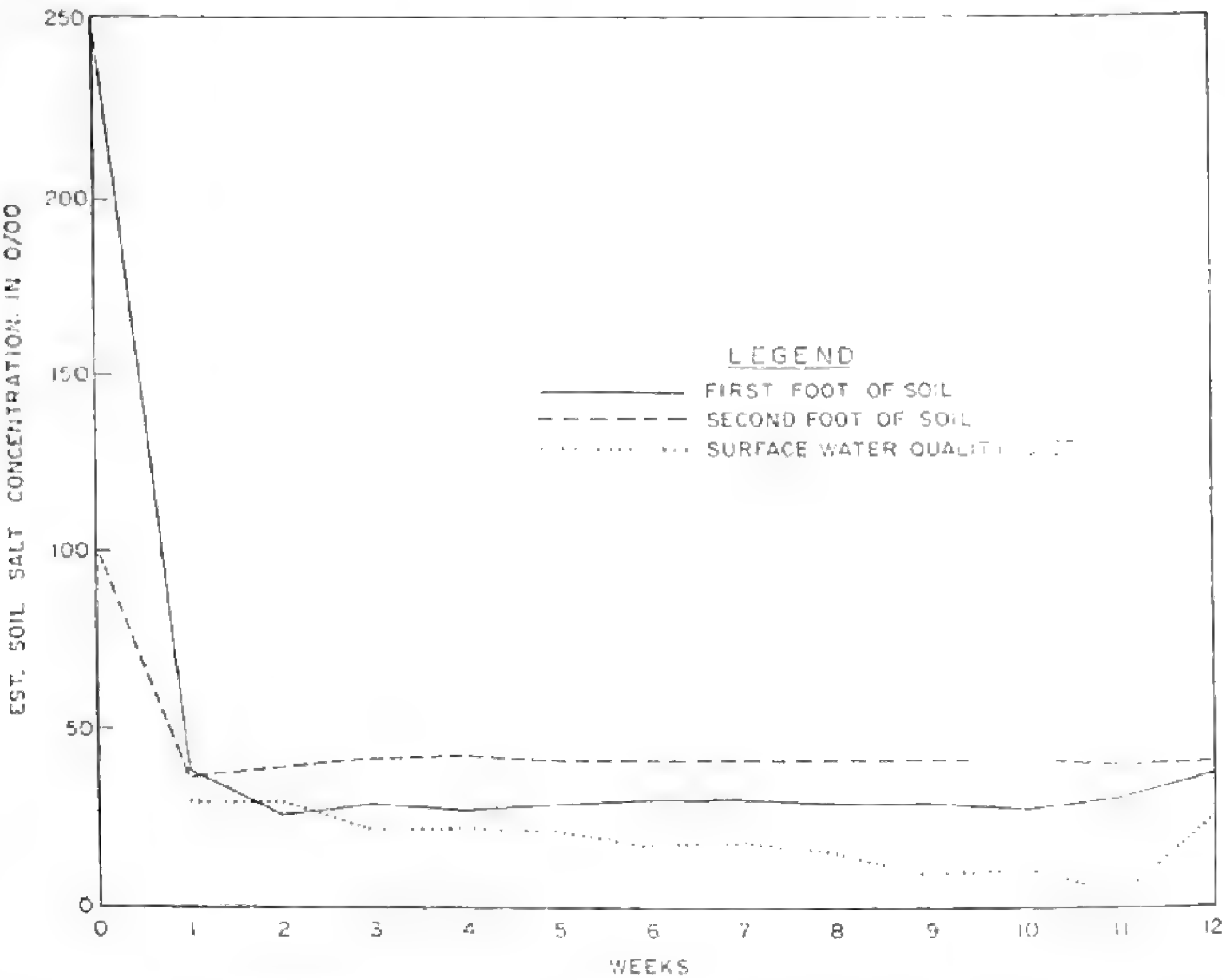


FIGURE 14. Weekly mean soil and surface water salinities occurring in the 20‰ infiltrometers during the 1969 supplemental test.

Natural Pond. The soil salinities of this site were not determined before flooding. The preflooding values depicted in Figure 15 are the same as those recorded for the 20‰ infiltrometers and are to be considered only as general reference points. Since this sampling site was located only 10 ft from the infiltrometers, the values are probably fairly accurate.

Large reductions in concentrations and amounts occurred in the first and second foot of soil following 3 weeks of flooding. Concentrations at both these depths stabilized at about 40‰ despite the fact that the surface water salinity remained constant at 8‰ throughout the test. Again, this is probably due to lack of draining and leaching.

It should be noted that the salinity of the water applied increased from an initial 3‰ to 8‰ due to the surface salt in the study pond. The results of the supplemental testing program demonstrate that flooding alone, even with relatively fresh water, is not sufficient to reduce highly saline soils to favorable salt levels for the production of alkali bulrush seed.

FIGURE 15. Weekly mean soil and surface water salinities occurring in the natural pond during the 1969 supplemental test.

SUMMARY

The water management regime of the four duck clubs studied is considered typical of water management practices throughout the marsh. This type of management produced extremely high late-summer soil salinities. The soil salinity in the first foot ranged from 80 to 146 total dissolved solids in September 1967. Apparently evaporation, transpiration, and other factors affecting moisture depletion were responsible for high salt concentrations and caused the movement of salt into the first foot from lower depths. The amount of salt in the second and third foot was relatively high and remained fairly stable throughout the year. This stable condition could be attributed to the lack of drainage. Salinity below the surface foot of soil changed very little, while in the first foot it fluctuated considerably and responded rapidly to flooding and drainage.

The application of relatively fresh water (2‰), in September 1967 produced a large reduction in soil salinity in the first foot depth. Soil salt concentrations were reduced by as much as 85% from 116‰ to 17‰ and salt amounts by 67%. After 2 months of flooding, salt levels stabilized and remained generally constant until spring drainage commenced. Spring drainage further reduced salt amounts by as much as 24%.

This study showed that on the test clubs, the application of relatively low salinity water in the fall followed by early spring drainage was

not adequate to achieve the desired soil salt concentrations of 9–14‰ in the first foot of soil in May as recommended by Mall (1969). Present water management practices in the marsh must be modified in order to favor the production of alkali bulrush and other desirable waterfowl food plants.

The infiltrometer study in 1968 and 1969 indicated a significant correlation between the salinity of the applied water and the resulting soil salinity in the first and second foot of soil. It was further established that the application of water with a salinity of approximately 20‰ resulted in significant increases of both soil salt amounts and concentrations.

Draining highly saline soils for 1 week and then reflooding them with relatively fresh water (3‰) for 2 weeks resulted in substantial reductions of soil salt amounts and concentrations at depths of 1 and 2 ft. This procedure reduced soil salt amounts and concentrations by 50% in the first foot and 28% in the second foot during Test Cycles I and II. During Test Cycle III, this procedure produced reductions in salt amounts and concentrations of 77% in the first foot and 63% in the second foot.

The application of saline water, of 10‰, to the study pond, produced no appreciable changes in soil salinity because the original soil salinities nearly equaled testing levels. Draining these soils for 1 week and then reflooding with relatively fresh water (3‰), reduced soil salt amounts and concentrations in the first foot by 75% and in the second foot by approximately 51% during Test Cycle III. Somewhat lesser reductions were produced by this procedure in Test Cycles I and II.

In a supplemental testing program designed to simulate normal late-summer conditions, the application of 20‰ water to extremely saline and dry marsh soils produced large initial reductions of soil salts. Two weeks later, after the soil had apparently become saturated, soil salinity levels stabilized. Soil salt levels remained constant despite a gradual reduction of surface water salinity from 20‰ to 4‰. This was attributed to the static water condition.

It was observed during this test that channel water salinities increased by 5‰ after entering the dry pond. This increase was the result of surface and subsurface salts dissolving into the newly applied water.

CONCLUSIONS

It has been predicted that as a result of upstream water diversions, the salinity of channel water in the Suisun Marsh area in 1990 will be from two to three times greater in the late spring and early fall than it is at present. The results of this study show that this increase in channel water salinities will result in substantial increases in soil salinities when the water is applied to the duck hunting clubs. As pointed out by Mall (1969), such widespread increases in soil salinities could be expected to reduce the amount of important waterfowl food plants and ultimately decrease the value of the Suisun Marsh as a waterfowl wintering area.

Most duck clubs in the Suisun Marsh drain their shooting ponds immediately following the waterfowl season in January and do not reflood until late September. The duck club phase of this investigation showed that this practice produced soil salt levels during the spring

and summer that discourage the growth of desirable waterfowl food plants. If this type of management is continued soil salinity conditions will worsen as channel salinities increase in the future.

This study has demonstrated that a single leaching cycle, using relatively fresh water of 2 to 3‰ total dissolved solids, resulted in substantial reductions of soil salts. Additional leaching cycles would probably have resulted in further salt reductions. The rate at which the soil salt was removed appears to have been dependent largely on the permeability of the soil, the efficiency of drainage and to some undetermined extent, the quality of the applied water. Obviously the limit of salt reduction by this method, even under ideal drainage conditions, is reached when the soil salinity equals the salinity of the applied water.

It is important to note that the dramatic results of leaching accomplished during this investigation cannot be applied directly to existing marsh conditions. The study pond was much smaller than any actual gun club shooting pond and drainage was relatively efficient.

Hence, it is concluded that a combination of improved management practices, improved drainage and control facilities and a supplemental supply of fresh water should all be considered to achieve the most efficient and economical means of attaining the desired soil conditions for waterfowl food plants.

Duck club operators and other marsh managers could improve waterfowl conditions in the marsh substantially at the present time by improving their facilities and water management programs. The following water management schedule has been formulated as a guide to duck club owners and operators to maximize waterfowl food production:

Fall Flooding: Consistent with Mosquito Abatement District regulations, flood in October as rapidly as possible to achieve the desired shooting level by the first day of the waterfowl season.

Pond Circulation: Inlet gates should be set to allow maximum water flow through all ponds during the waterfowl season, while maintaining the water at shooting level.

Post Season Draining: Post season draining should begin either on or slightly before the last day of the hunting season (usually in early January). Close all inlets, remove all flashboards, and allow ponds to drain as rapidly as possible.

Post Season Flooding: Reflood as soon as the ponds have drained, even if a few hard to drain areas still contain water. Open all inlets and allow the water to rise quickly to one-half shooting depth.

Spring Leaching Cycles: Begin to drain ponds as soon as the required level has been reached. This flood-drain cycle should be repeated as least two times to leach salt from the soil. Leaching is far more effective than circulation for removing soil salt.

Final Spring Flooding: The leaching cycles should be timed such that by no later than April 1 water levels are stabilized at one-half shooting depth.

Pond Circulation: Circulate by setting the inlet gates and flashboards to allow maximum flow through the ponds without increasing the water depth. Extreme care must be taken to eliminate fluctuations in pond levels which would favor the propagation of mosquitoes.

Summer Drainage: Drain during the first week of June, when the majority of alkali bulrush and other waterfowl food plants have set seed. Close inlets, remove flashboards, and allow complete drainage.

ACKNOWLEDGMENTS

This investigation was part of the Delta Fish and Wildlife Protection Study financed by the Department of Water Resources under a contract with the Department of Fish and Game.

John Skinner, Research Supervisor, who directed the program, provided much sound advice during both field and report writing stages of this study and was largely responsible for its smooth operation.

I am indebted to Rolf Mall, project leader during the first half of this study, for his guidance in technical matters and his instruction on the complex ecology of the Suisun Marsh. I would further like to thank Rolf for his cooperation in the operation of the study pond on Joice Island Wildlife Area.

Technical and engineering assistance was provided by the Department of Water Resources. Glenn Twitchell acted as advisor and liaison, and maintained an excellent working relationship between the two departments.

Arthur deRutte, who succeeded Twitchell, spent many long hours designing and maintaining the physical structures and techniques so necessary for the successful operation of this program. Art also assisted in the editing of this report.

I am very grateful to Richard Wada who collected most of the soil moisture data; to George Siller, Robert Berry, Rudy Solorio, and others who also assisted in the field.

Special thanks to Dr. Falih Aljibury, irrigation and salinity expert with the University of California Agricultural Research Station at Reedley, California, for his many helpful suggestions during the editing of this manuscript.

Mrs. Janet Boranian handled most of the clerical work during this study and typed the preliminary drafts of this report. Her diligence and cheerful disposition, even during the most trying of times, were very much appreciated.

I would also like to thank Mrs. Marlene Oehler and Mrs. Clarice Chism for their clerical assistance.

Several college students helped me with the field and laboratory work. They were: Jay Jones, Dan Price, Mike Dunham and Steven Klaffke. I would like to thank my wife Pamela for her efficient operation of the laboratory in Phase I and for her patience and many helpful suggestions during the writing of this report.

I would like to extend my thanks to the owners and operators of the Teal, Shelldrake, Family and Northend Duck Clubs for their cooperation during Phase I of this investigation.

REFERENCES

Alder, H. L. and Roessler, E. B. 1960. Introduction to probability and statistics. W. H. Freeman and Company, San Francisco, California. 313 p.

Arend, Philip H. 1966. *In* Final reports phases 1 and 2. Suisun Soil Conservation District, Solano County, California. Simpson, Stratta and Associates and Karl H. Baruth, San Francisco, California.

California Department of Water Resources. 1960. The Delta and the Delta water project. Calif. Dep. of Water Resources, Sacramento, Calif. 22 p.

——— 1967–1969. Monthly salinity observations, Sacramento–San Joaquin Delta and upper bays.

Chapman, V. J. 1960. Salt marshes and salt deserts of the world. Interscience Publishers, Inc., New York, N.Y. 392 p.

Ezekiel, Mordecai and Karl A. Fox. 1950. Methods of correlation and regression analysis. John Wiley and Sons, Inc., New York, N.Y. 548 p.

George, Harry A., William Anderson and Harold McKinnie. 1965. An evaluation of the Suisun Marsh as a waterfowl area. Calif. Dep. of Fish and Game, Admin. Rep. [illegible] p.

Jepson, W. L. 1925. A manual of the flowering plants of California. Univ. of Calif. Press, Berkeley, Calif. 1,238 p.

Luebs, R. E., M. J. Brown and A. E. Laag. 1967. Determining water content of different soils by the neutron method. Soil Science 106: 207–212.

Mall, Rolf E. 1962. *In* Delta fish and wildlife protection study. Rep. No. 1.

——— 1969. Soil-water-salt relationships of waterfowl food plants in the Suisun Marsh of California. Calif. Dep. of Fish and Game. Wildlife Bull. No. 1, 59 p.

Mason, Herbert L. 1957. A flora of the marshes of California. Univ. of Calif. Press, Berkeley, Calif. 878 p.

Skinner, John E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Calif. Dep. of Fish and Game, Water Projects Branch Rep. No. 1. 225 p.

United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U. S. Dep. of Agric., Handbook No. 60. 160 p.

Van Bavel, C. H. M. 1961. Neutron measurement of surface soil moisture. J. Geo-phys., Res. 66: 4193–4198.

Van Bavel, C. H. M., P. R. Nixon and V. L. Hauser. 1963. Soil moisture measurement with the neutron method. Ag. Res. Serv. 41–70, 39 p.

Calif. Fish and Game, 59(1): 36–61. 1973.

BIOMASS ESTIMATES OF SPAWNING HERRING, *CLUPEA HARENGUS PALLASI*, HERRING EGGS, AND ASSOCIATED VEGETATION IN TOMALES BAY [1]

JAMES E. HARDWICK
Marine Resources Region
California Department of Fish and Game

Tomales Bay is an important central California habitat and a spawning ground for several species of fish. A minimum of 1,600 tons of herring enter the bay each winter to spawn. They lay at least 163 tons of eggs, primarily upon eelgrass, *Zostera marina*, which comprises 75% of the vegetation of the bay. Eggs also are deposited on rocks and algae. Herring eggs on edible seaweed are harvested, and it is recommended that this annual harvest not exceed 20 tons.

INTRODUCTION

Since 1965 applications have been made to the Fish and Game Commission for permission to harvest herring eggs on edible seaweed in Tomales Bay. The Department of Fish and Game has recommended that a take of 5 tons would be very conservative and would pose no threat to either the herring or the seaweed resources. During 1970 a study was initiated to determine the quantity and composition of aquatic vegetation in the bay, the size of the herring population spawning in the bay, the weight of eggs spawned, and to determine the effect the herring egg-on-seaweed fishery has on the resources of the bay.

Since the study was initiated, the devaluation of the dollar and the removal of the Japanese quota on herring roe imports (Shohara, 1972) also has made the harvest of spawning herring for the production of "kazunoko" economically feasible. A number of individuals are investigating the possible exploitation of this resource at the present time. The results of this study now have relevance to this potential fishery as well as the herring egg-on-seaweed fishery.

PHYSIOGRAPHY OF TOMALES BAY

Tomales Bay is 40 miles (64 km) northwest of San Francisco at the southeast end of Bodega Bay (Figure 1). The San Andreas fault extends down the center of the bay along its length. The western shore of the bay is composed of granite rock overlain by tertiary sediments (middle Miocene siliceous shales, sandstones, and cherts; Paleocene conglomerates and siltstones; and some lower and middle Pliocene sandstones and diatomaceous siltstones). The eastern shore consists of sandstones and associated igneous rocks of the Franciscan formation with minor amounts of conglomerate, chert, shale, metamorphic, and diabase bodies. Outcrops of Franciscan sandstone occur at Toms Pt., Hog Island, and on the floor of the bay southeast and east of Hog Island. Sand Pt. and portions of Toms Pt. consist of sand dunes. The bay is 12.5 miles

[1] Submitted for publication July 1972.

(20.4 km) long and 0.4 to 1.5 miles (0.7 to 2.7 km) wide. Its area at mean lower low water is 11 square miles (28.5 km^2); the average depth is 12 ft (3.7 m), and greatest depth is 60 ft (18.5 m). The volume of the bay is 4×10^9 ft^3 (1.1×10^8 m^3) at mean lower low water (Johnson, Bryant, and Hedgpeth, 1961; Daetwyler, 1966).

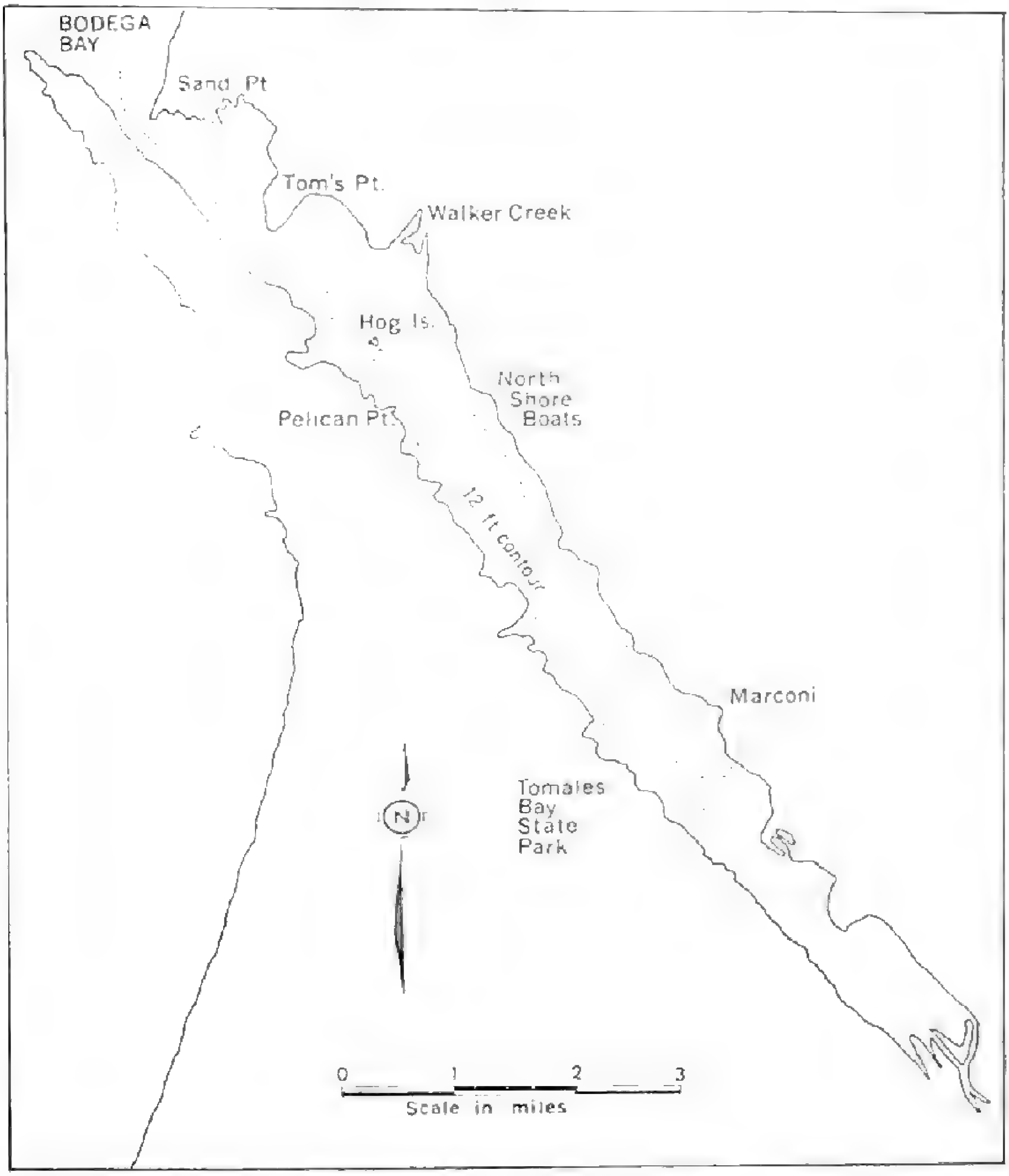


FIGURE 1. Principal landmarks along shoreline and 12 ft depth contour of Tomales Bay.

North of Pelican Pt. a deep channel follows the contours of the western shoreline with subsidiary channels draining the shoals to the east. These shoals are covered from mean lower low water to depth of 10 ft with vegetation, primarily eelgrass, *Zostera marina*. Although light penetrates to the bottom, there is no vegetation in the channels because strong tidal currents scour the bottom. A strip of marine vegetation less than 200 yards wide is found along the western shoreline. Bottom

sediments primarily consist of sand with the coarser sands found in the deep channel close to the western shoreline. Temperature, salinity, and transparency are like that of the adjacent ocean except near the mouth of Walker Creek. Over the shoals, dissolved oxygen concentrations vary considerably between day and night as a result of photosynthesis and plant respiration.

South of Pelican Pt. the shoals on the eastern side of the bay narrow to 100 to 500 yards. Depth contours of this portion of the bay are more symmetrical about its longitudinal axis than those north of Pelican Pt. Light penetration is poor and marine vegetation is restricted to a narrow strip along the shoreline. This strip is less than 100 yards wide at most points between Pelican Pt. and Tomales Bay State Park on the western shore and North Shore Boats and Marconi on the east shore (Figure 1). South of Marconi and Tomales Bay State Park lies another shoal inhabited by *Polysiphonia* and *Enteromorpha*. The sediments south of Pelican Pt. consist of mud and muddy sand. Salinity and temperature vary considerably with precipitation, air temperature, humidity, and wind velocity. Dissolved oxygen concentrations range from 3.06 to 8.46 ml/liter.

HISTORY OF TOMALES BAY HERRING FISHERIES

During and for a short time after World War I (1917–1919) comparatively large quantities of herring were landed for canning and for reduction to fish meal and oil. The canned product was exported to Europe. The State Reduction Act of 1919 which prohibited the use of fish for reduction without Fish and Game Commission permission and a reduced demand for canned herring combined to reduce landings to less than half a million lb. annually until 1948 (Figure 2), when San Francisco canners began buying herring in an attempt to fill the demand created by the scarcity of sardines (Hughes, 1949). Previous to 1952, herring were caught with gill nets set in a circle around a school, and beach seines set on herring spawning in the shallows. Nine lampara launch and lighter boats from Monterey began fishing herring in Tomales Bay in the winter of 1952 (Scofield, 1952). Requests for permits to reduce herring were denied in 1954 and 1955 by the Fish and Game Commission. As a result of the 1954 requests for permits to reduce herring, the California Department of Fish and Game initiated a study of California's herring resource. This study yielded estimates of 4,000 tons of spawners in Tomales Bay and 16,000 tons of spawners in San Francisco Bay (Miller and Schmidtke, 1956). The Department also recommended that reduction of herring not be allowed in California. Herring continued to be canned but in decreasing amounts. Annual herring landings fell to less than 3,000 lb. in 1964 and have remained below 12,000 lb. ever since.

In 1965 the Fish and Game Commission granted a permit to harvest 5 tons of herring eggs on seaweed from Tomales Bay. This harvest was permitted between December 1, 1965, and March 31, 1966. Similar requests were granted through March 1970.

When the request to harvest herring eggs on seaweed was first received by the Department in 1964, the possible effects of the proposed fishery upon the natural resources of the area were investigated. It was decided that if the size of the herring resource of Tomales Bay

TOMALES BAY HERRING CATCH

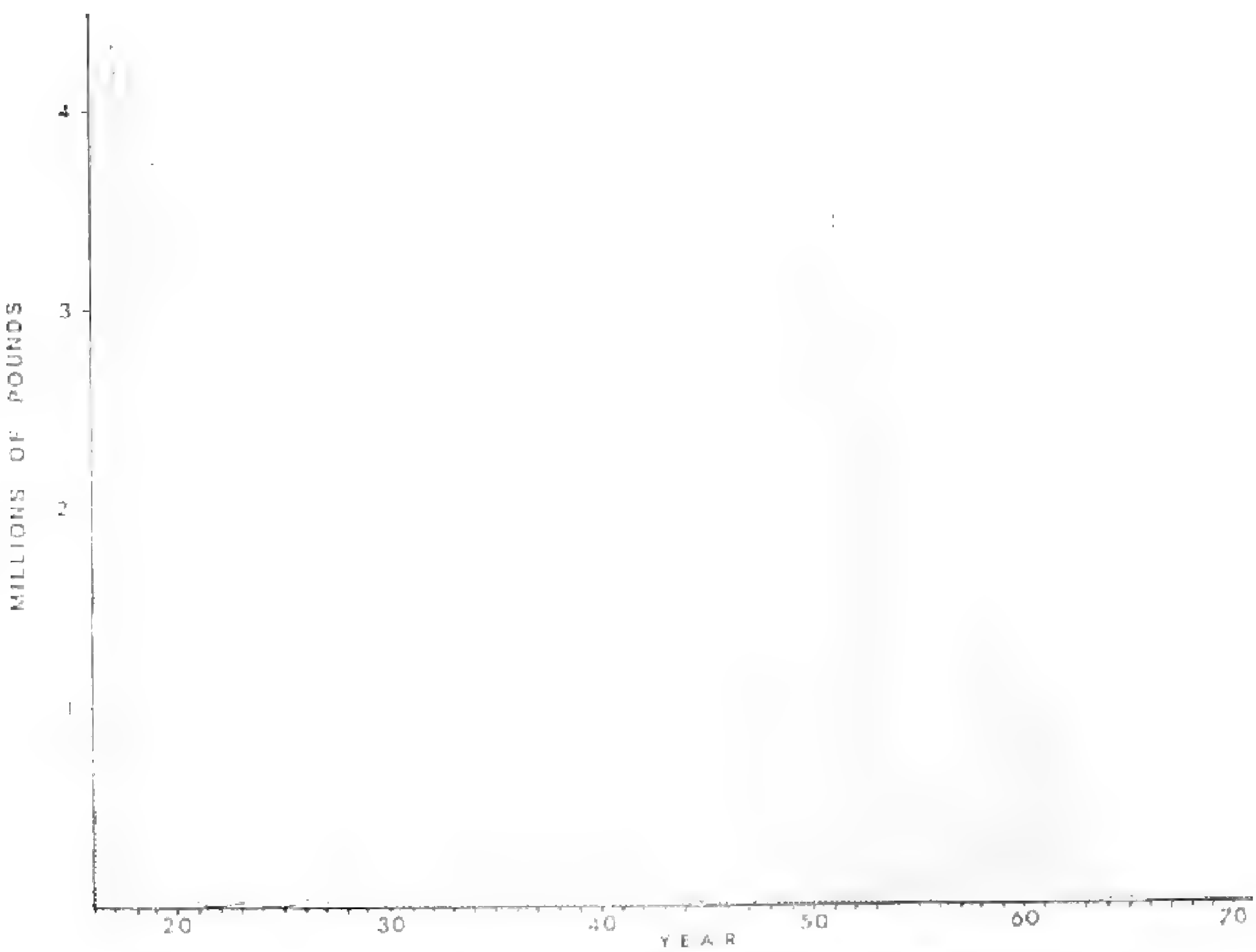


FIGURE 2. Annual landings of herring caught in Tomales Bay, 1916–1971.

was anywhere near the 4,000 tons reported in 1955 (Miller and Schmidtke, 1956), a 5 ton harvest of herring eggs on seaweed would cause no harm to that resource.

HERRING BIOLOGY

Life History

The Pacific herring, *Clupea harengus pallasi*, ranges from central Japan northward into the Bering Sea and south along the Pacific coast of North America to northern Baja California. In California herring spawn in estuaries and bays. While no herring have been tagged in California waters, tagging studies in Canada (Stevenson, 1955) and Alaska (Rounsefell, 1930) have shown that these fish exhibit a "homing instinct" which brings them back to spawn in the place where they hatched. Herring mature at 3 to 5 years of age and spawners begin entering bays and estuaries in late November and December. Large herring enter at the earliest dates with smaller spawners following. Miller and Schmidtke (1956) reported herring schools spawn between December and June at depths between the midtide level and about 36 ft (11 m); however, all spawn I have seen in Tomales Bay occurred between mean higher low water and 12 ft (4 m) below mean lower low water. The spawning season begins and ends earliest at the most southern regions of the Pacific herring's range and latest in the more northerly portions. Several spawnings usually occur

at each locality during the spawning season, although each individual herring spawns only once.

In comparing California herring with those to the north, Miller and Schmidtke (1956) made the following statement:

> "Herring in Californian waters do not attain as great a size nor do they live as long as the herring farther north. The largest recorded herring from California was a female 224 mm in standard length (approximately 10½ inches total length) but larger herring, up to 11½ inches total length, have been reported by fishermen.
> Herring in Alaska have been known to live 19 years, but the oldest herring taken in California (San Francisco Bay) was only nine years old. The growth rates of Tomales Bay herring, caught in 1955 (as computed from calculated lengths by use of age rings on scales) differ from Alaskan herring (Rounsefell, 1930). Herring in Canada and Alaska are spawned later and in colder water, resulting in a shorter and slower growing period for the first year. Not until after the second year's growth do herring to the north attain a size comparable to Californian herring of the same age. After the second year Canadian and Alaskan herring grow faster, reach a much greater size, and live longer than do herring in California."

The fish may remain in Tomales Bay up to 2 months before spawning. During this time they school in the deepest areas of the bay until 1 or 2 days before spawning. They then swim into shallow areas where they spawn on whatever substrate is available, which in Tomales Bay is usually eelgrass with occasional spawnings on surfgrass, *Phyllospadix*, or algae (*Gracilaria*, *Polysiphonia*, or *Ulva*). In spawning the female swims parallel to and directs eggs towards the substrate upon which eggs are to be deposited (Maxwell B. Eldridge, National Marine Fisheries Service, pers. comm.). The eggs readily adhere to any surface they contact. Miller and Schmidtke (1956) state that herring eggs are "not sticky-to-the-touch." This is true of eggs several hours after spawning and of eggs in immature herring, but eggs of ripe herring adhere to my hand (usually in a single layer) and are difficult to wash off. It is not uncommon to find eggs more than one layer thick on vegetation. I suspect the interior layer of eggs were spawned before the outer layer since eggs I have taken from ripe herring did not stick to each other, and the spawned eggs below an outer layer are frequently decayed. Careful observation of the age of eggs spawned in different layers might confirm or refute my inference.

Spawning occurs during the day as well as at night (Maxwell B. Eldridge, National Marine Fisheries Service, pers. comm.) and in a single locality may last for anywhere from a few hours to several days. In Tomales Bay the herring return to the sea immediately after spawning. The eggs hatch in 6 to 11 days in water at 46.4 to 50.0 F (8 to 10 C).

Fecundity

Forty-two herring caught in Tomales Bay with a 1¾ inches stretched mesh gill net in mid-January 1972, were sampled for length, weight, sex, and oviduct weight (Table 1). The oviducts of each of the 10 female herring present in the two samples were preserved in 10% formalin. Oviducts were rinsed in freshwater and weighed again when removed from the formalin, and 1 g of eggs from each oviduct counted. The mean number of eggs per unit weight of oviduct was calculated for each fish. While most gonads changed little in weight while in formalin, some gained and some lost weight.

TABLE 1. **Number of Eggs Per Female Herring**

Length (mm SL)	Weight grams	Weight of oviduct (g)	No. of eggs oviduct/gram	Total No. of eggs	No. of eggs per gram of fish
166	76.1	16.9	892 ± 9	15,100	198
176	102.0	23.7	1183 ± 11	28,000	275
177	98.8	29.6	999 ± 92	29,600	300
185	98.6	19.4	959 ± 85	18,600	189
186	105.6	20.1	899 ± 34	18,100	171
187	114.3	24.2	1121 ± 117	27,100	237
190	122.4	23.5	822 ± 43	19,300	158
191	120.9	25.2	1286 ± 25	32,400	268
203	148.2	29.9	991 ± 83	29,600	200
208	156.5	34.8	1239 ± 28	43,100	275

The mean number of eggs per unit weight of oviduct was multiplied by the total weight of the two oviducts to obtain the number of eggs in each fish. This figure was divided by the total weight of the fish to yield the number of eggs per unit weight of each female herring (227 ± 50 eggs/g).

In my sample of 42 herring, only 10 were females; however, the sex ratio of 4.0 ± 2.8 males per female was not significantly different from a 1:1 sex ratio. To check this sex ratio, 408 herring were examined. This examination revealed a sex ratio of 1.34 ± 0.45 males per female; again not significantly different from a 1:1 ratio.

The mean weights of the 42 herring initially sampled were 114 (SD:24) g for females and 119 (SD:20) g for males. Since these data show no significant difference between the weight of males and females, I assume female herring compose 50% by weight of the total herring spawning biomass; and by dividing the number of eggs per gram of female herring by two, the number of eggs per gram of spawning herring (114 ± 25) can be estimated without regard to sex.

My data compare favorably with the findings of Hart and Tester (1934) who determined that 18,000 eggs and 29,500 eggs were deposited by British Columbian female herring averaging 192.5 and 223 mm SL, respectively.

Unfortunately, the only herring available for sampling in Tomales Bay were caught by gill net. This gear selects for fish 170 mm SL and larger. Nearly half the spawning herring in Tomales Bay are smaller than 170 mm SL (Miller and Schmidtke, 1956). My own fecundity data indicate the number of eggs per unit weight of fish is proportional to the size of the fish. Therefore, my estimate of 103 million eggs per ton of spawning herring is probably somewhat larger than the actual figure. This produces a conservative estimate of spawning biomass.

POPULATION ESTIMATES

Methods

Subsequent to the 1954–55 requests for permits to reduce herring, the Department initiated a study of the herring resource. Miller and Schmidtke (1956) made estimates of the number of herring eggs spawned in Tomales and San Francisco bays using methods developed by Hart and Tester (1934) and Hourston (1953). They projected their egg estimate into a population estimate using eggs per spawner data of Hourston (1953).

Using a barge powered with an outboard motor and a device they designed to sample aquatic vegetation (the heads of two garden rakes welded back to back with a solid steel bar welded to the backs of the two rake heads), Miller and Schmidtke crisscrossed Tomales Bay 1 to 2 days each week in late 1954 and early 1955, dropping and retrieving their aquatic vegetation sampler in search of vegetation veneered with herring eggs. The location of vegetation to which herring eggs had adhered was recorded as well as relative density of eggs upon the vegetation (Table 2). Eggs were collected to permit them to determine dates upon which spawning had taken place. Most of the herring eggs Miller and Schmidtke found were south of Pelican Pt. where vegetation is restricted to a narrow band adjacent to the shoreline (Figure 3).

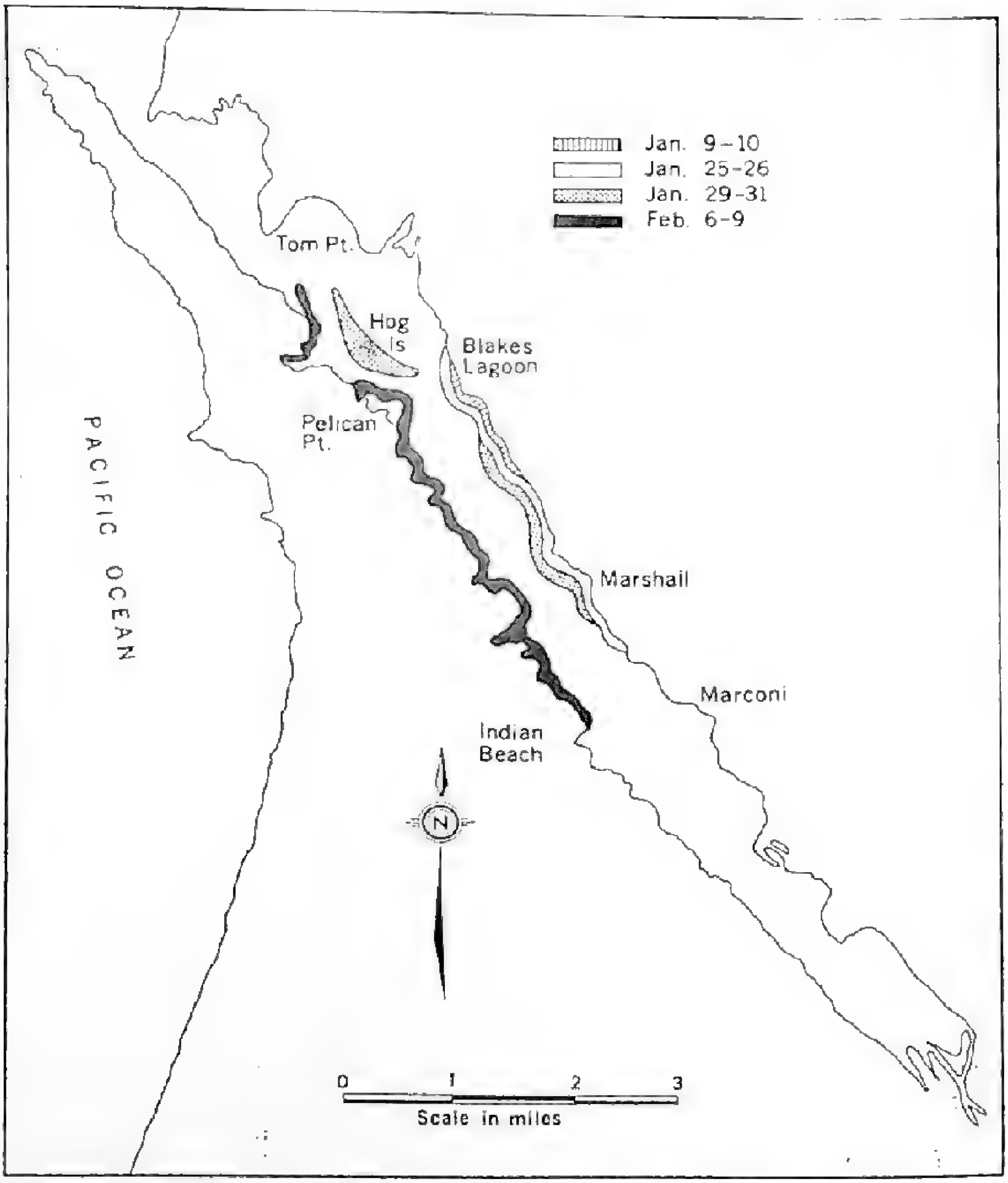


FIGURE 3. Distribution of herring spawn found by Miller and Schmidtke in 1955.

In order to estimate the area covered by eggs, they multiplied the linear yards of spawning by 20 to obtain the square yards of spawning on the assumption that the band of vegetation averaged 20 yards in width. The number of eggs spawned was calculated by multiplying the square yards of spawning area by the appropriate number of eggs per square yard. Hourston (1953), using echo-sounding techniques, estimated that 18,000 tons of herring spawned 1,056,500 million eggs, or 59 million eggs per ton of herring. Miller and Schmidtke used this information to calculate herring biomass from their egg estimates.

TABLE 2. Number of Eggs at Different Intensities of Spawn Deposition *

Intensity	Number of eggs per inch of *Fucus* or linear inch of other vegetation	Number of eggs per yard
Very light	1– 49	7,000
Light	50–199	246,000
Medium	200–499	1,009,000
Heavy	500–999	1,369,000

* From Hourston, 1953.

I estimated the number of herring eggs spawned and the herring spawning biomass in 1971 using, with one exception, the methods of Miller and Schmidtke. Spawning during the winters of 1971 and 1972 was centered on the subtidal flats in the vicinity of Hog Island (Figures 4 and 5) and not parallel to a shoreline with a narrow band of suitable spawning substrate. It was not possible under these circumstances to determine the area of spawning by multiplying the linear measurement of spawning by 20 yards. As a result, I was forced to develop another method of determining size of spawning area.

The location of each station at which the Miller and Schmidtke aquatic vegetation sampler was dropped was determined by triangulation, using a compass to determine the direction from landmarks on shore and when possible aligning points on Hog Island with points on the shore beyond the island. In this manner the boundary of a spawning can be estimated within 300 ft (100 m) of the actual boundary within which spawning takes place. From these station data each spawning was mapped on U.S. Coast and Geodetic Survey chart 5603 and the area determined using a polar planimeter. All other estimates were made in the same manner as those of Miller and Schmidtke. A number of assumptions made in the 1955 and 1971 surveys remained untested, and the difference in number of eggs per unit area between various spawning intensities seemed too great for comfort.

The survey was repeated in 1972 using both old methods and new methods designed, consistent with the manpower available, to leave as few doubts as possible concerning the estimates. The area of spawning was determined in a manner similar to that used in 1971 (Figure 5).

The number of eggs per unit area was separated into three groupings: (i) number of eggs per unit weight, (ii) weight of eggs per unit weight of vegetation, and (iii) the weight of vegetation per unit area.

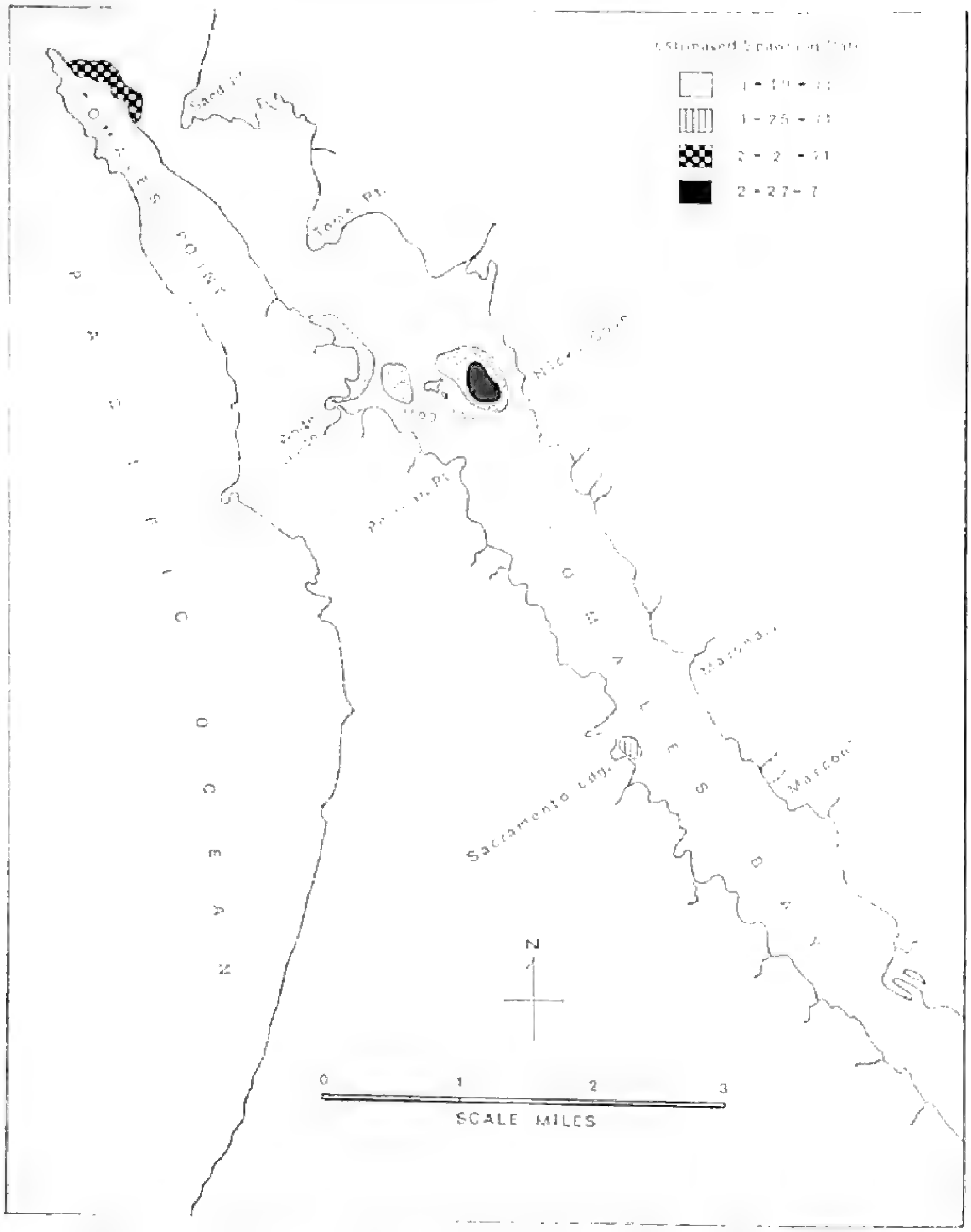


FIGURE 4. Distribution of herring spawn in 1971.

A sample of vegetation and eggs was taken at each station at which the Miller and Schmidtke aquatic vegetation sampler contained vegetation with herring eggs adhering to it. The sample was placed in a plastic bag with a small volume of 100% formalin.

Samples were analyzed within 1 or 2 weeks of collection. The sample was washed in freshwater and a subsample of 50 to 100 g taken. Eggs were stripped from vegetation and weighed to determine egg-vegetation weight ratio. Three 1 g samples of eggs from spawnings prior to January 14 were counted to obtain an estimate of the number of eggs

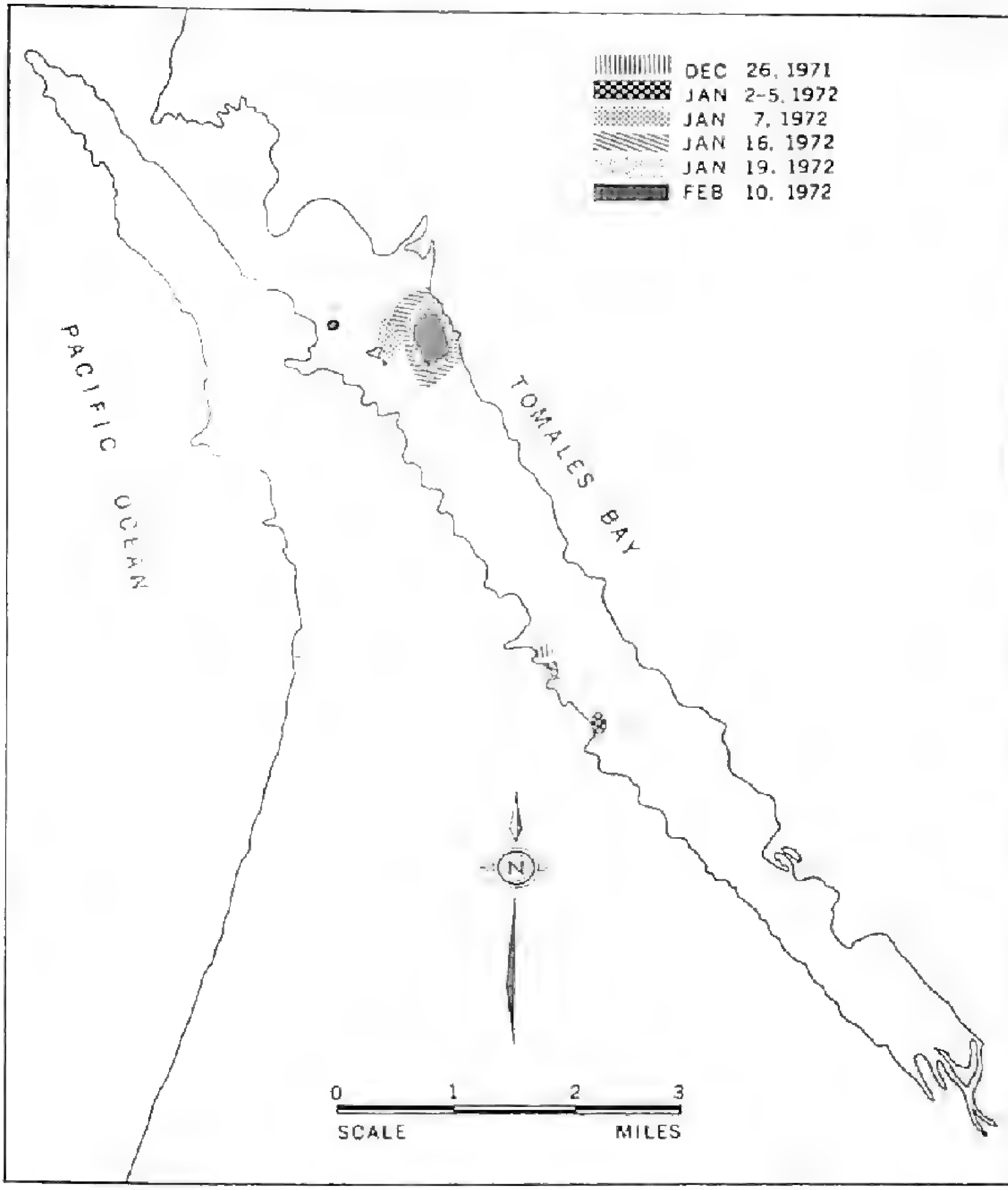


FIGURE 5. Distribution of herring spawn in 1971–72.

per unit weight. Subsequent to January 14, I determined the ratio of wet egg weight to dry weight and weighed two samples of 500 dried eggs. The date of spawning was determined by microscopic examination of these eggs. I found that a billion eggs weigh about 1 ton.

The weight of vegetation per unit area was determined in the eelgrass beds to the north and east of Hog Island by weighing the vegetation collected in each of 12 randomly selected m^2 quadrats. Eelgrass and associated epiphytes were the only plants sampled. No attempt was made to separate epiphytes from eelgrass. A grid with lines scaled to 100 yards apart was superimposed upon a chart of Tomales Bay. Squares of the grid were designated by a coordinate system and pairs of numbers were chosen from a random number table. Those squares

which fell within the area where eelgrass beds occurred were sampled. Sampling was conducted from a 14 ft aluminum skiff the morning of March 19, 1972, while there was a moderately low tide. At each station the skiff was anchored and a hoop containing an area of 1 m^2 was thrown from the skiff. Eelgrass leaves upon which the hoop lay were pulled from under the hoop so that the hoop lay on the mud at the base of the plants. All vegetation within the hoop was then pulled up and placed in a plastic bag.

RESULTS

Miller and Schmidtke estimated that 230 billion eggs were spawned in Tomales Bay in 1955 (Table 3), and I estimated that 255 billion eggs were spawned in 1971 (Table 4). In 1972, using traditional methods I estimated 342 billion eggs were spawned (Table 5). However, using my new methods I estimated 163 billion eggs were spawned (Table 6), approximately half the estimate obtained using the old method.

If the new method of estimating the number of eggs spawned is accepted as being more precise, this indicates former estimates were excessive by a factor of two. This would be a dangerous interpretation since each method could produce an estimate that may be erroneous by a factor of one.

Within the spawning intensities categories, there are large variations. For example, within the "very light" category there is variation by a factor of 50 between the lowest and highest intensity spawnings assigned to this category, and within the light category there is variation by a factor of four. Spawnings in Tomales Bay most often fall into one of these categories.

Variation in estimates produced by the new method also are large. The standard deviation of egg weight per vegetation unit weight estimates are particularly large and could be reduced only by a considerably increased expenditure of manpower and funds which would allow stratification of spawning areas by intensity of spawning. More frequent and intensive sampling of eelgrass beds for weight of vegetation per unit area would reduce the standard deviation of this parameter. It was not possible to calculate a standard deviation for the area of each spawning.

The number of significant figures provide some idea of my confidence in these estimates. Considering the standard deviations of the parameters used to calculate the number of eggs spawned, the various estimates are remarkably similar and the differences cannot be interpreted as significant. The most recent egg estimate is definitely minimal and possibly not as accurate as earlier estimates since an important parameter still is unknown; the amount of predation on the eggs. My estimate of egg number makes no provision for any predation. Outram (1958) reported that 30 to 55% of the herring eggs spawned in British Columbia waters were eaten by birds, primarily glaucous winged, *Larus glaucescens,* and western gulls, *Larus occidentalis.* People who harvest herring eggs in California locate recent spawnings by sighting feeding gulls. I have seen gulls and ducks feeding in the vicinity of recently spawned herring eggs. Some of these birds were California gull, *Larus californicus;* mew gull, *L. canus;* glaucous winged gull; western gull; coot, *Fulica americana;* and surf scooter, *Melanitta perspicillata.*

TABLE 3. Number of Herring Eggs Spawned in San Francisco and Tomales Bays in 1955, Based on Canadian Measures of Eggs Per Square Yard

Intensity	Canada	San Francisco Bay			Tomales Bay		
	Eggs per square yard	Linear yards	*Square yards	Number of eggs	Linear yards	*Square yards	Number of eggs
Very light	7,000	200	4,000	28,000,000	2,000	40,000	280,000,000
Light	246,000	1,500	30,000	7,380,000,000	10,500	210,000	51,660,000,000
Medium	1,009,000	16,800	336,000	339,024,000,000	8,800	176,000	177,584,000,000
Heavy	1,369,000	13,100	262,000	358,678,000,000			
Total				705,110,000,000			229,524,000,000

* Linear yards multiplied by 20.

TABLE 4. Number of Pacific Herring Eggs Spawned in Tomales Bay in 1971

Spawning	Date	Square yards	Eggs per square yard	Number eggs	Estimated spawning population (tons)
1	Jan 19	1,530,000	7,000	10,710,000,000	180
2	Jan 25	10,000	1,369,000	13,690,000,000	240
3	Feb 2	82,000	1,009,000	82,738,000,000	1,410
4	Feb 27	612,000	246,000	150,552,000,000	2,570
Total				257,690,000,000	4,400

TABLE 5. The Number of Pacific Herring Eggs Spawned in Tomales Bay in 1972 *

Date of spawning	Square yards	Eggs per square yard	Number of eggs	Spawning population (tons)
Dec 26	50	246,000	12,000,000	0
Jan 2–5	600,000	246,000	148,000,000,000	2,500
Jan 2–5	1,200	7,000	8,000,000	0
Jan 10–13	550,000	246,000	135,000,000,000	2,300
Jan 15–19	5,400	1,009,000	5,400,000,000	90
Feb 10	218,000	246,000	53,600,000,000	900
Feb 10	21,800	7,000	153,000,000	3
Total			342,173,000,000	5,793

* Calculated by method used by Miller & Schmidtke (1956).

Fish and invertebrates are another source of predation. Tokihido Ichinose, a commercial harvester of herring eggs-on-seaweed, told me that while diving adjacent to Racoon Strait in San Francisco Bay he has observed the following animals eating herring eggs: sturgeon, *Acipenser* sp.; smelt (Family Atherinidae), surfperch (Family Embiotocidae), and crabs (probably *Cancer* sp.). Outram estimated total predation on herring eggs at 56 to 99%, the higher rates being on more extensive spawnings. He found that 66% of predation occurs within 3 days of spawning.

The extent of predation varies greatly from one spawning to another. On three occasions I was able to make two separate visits to a site of a spawning; the first immediately after spawning, and the second 5 to 7 days later. In one case there were no eggs left by the time of my second visit, and on the two other occasions there was only 10% of the original eggs left. Some of my estimates were made 5 and even 6 days after the spawning (Table 6). These estimates may represent as few as 10% of the original number of eggs spawned.

In calculating the weight of spawners required to produce the number of eggs found, Hourston (1953) estimated the number of eggs

TABLE 6. Estimate of Herring Spawn in Tomales Bay During the Winter of 1971–1972

Date of spawning	Egg age (days)	Kind of vegetation	Egg weight (g) per kilogram vegetation	Weight veg. (kg) per M²	Spawning area (M²)	Percent bottom with veg.	Weight of eggs (kg)	Number of eggs per gram	Millions of eggs	Tons of herring
Dec. 26, 1971	6	Gracilaria	335 ± 88	0.5	10	100	7	505 ± 77	3	0
Jan. 2-5, 1972	2–5	Zostera	189 ± 112	1.6 ± 0.7	501,060	83	126,590	332 ± 72	51,618	531
Jan. 2-5, 1972	2–5	Zostera	10 ± 9	1.6 ± 0.7	1,000	83	13	411 ± 68	6	0
Jan. 10-13, 1972	3–6	Zostera	182 ± 173	1.6 ± 0.7	450,000	83	110,938	422 ± 34	46,816	455
Jan. 15-19, 1972	1–5	Zostera	977 ± 922	1.6 ± 0.7	1,500	83	6,211	397 ± 83	2,466	24
Feb. 10, 1972	2	Zostera	555 ± 122	1.6 ± 0.7	180,000	83	132,667	412 ± 78	58,639	569
Feb. 10, 1972	2	Zostera	43 ± 27	1.6 ± 0.7	18,000	83	10,279	411 ± 61	422	4
Total									163,000	1,583

spawned in the traditional manner, and the weight of herring by echo-sounder traces. This method produced an estimate of 59 million eggs per ton of herring; a considerably smaller estimate than the 103 million eggs per ton of herring which I calculated by counting the eggs in herring. Hourston's estimate may more accurately reflect the number of spawners because a large percentage of the eggs spawned cannot be counted due to predation.

Spawning population estimates for 1955 and 1971 were approximately 4,000 tons for both years based on traditional egg estimates and Hourston's ratio of eggs per ton of spawners. Using traditional egg estimation methods, and the ratio of eggs per ton of spawners developed from my fecundity data, I estimated there were 2,200 tons of spawners in 1955 and 2,500 in 1971. Estimates of the number of spawners in 1972 vary from 6,000 tons using traditional egg estimation methods and Hourston's ratio of eggs per ton of spawners to 1,600 tons using the new methods. Most of these estimates appear to be low since the annual catch of herring from Tomales Bay exceeded 1,500 tons from 1951 to 1953 and 500 tons from 1958 to 1960 without any obvious decline in abundance.

VEGETATION IN TOMALES BAY

The herring egg-on-seaweed fishery harvests seaweed as well as herring eggs. The seaweed harvested in Tomales Bay with herring eggs is a member of the genus *Gracilaria*. An estimate of *Gracilaria* biomass in the bay, information concerning the growth rates of this plant, and a knowledge of its life history are prerequisites to a harvest quota recommendation. An understanding of the special and quantitative relationship between *Gracilaria* and other Tomales Bay vegetation provides a baseline for detecting potential changes in the bay's vegetation. A study was designed to determine the quantity and species composition of aquatic vegetation in the bay and to postulate the affects a herring egg-on-seaweed fishery might have on associated vegetation.

Methods

In October 1970, a training session for Department divers was combined with an analysis of the vegetation of Tomales Bay. Twenty-three Department divers and one National Parks Service diver participated in the survey. An area was surveyed from the commercial fishing closure boundary to a line perpendicular to the shore at Inverness General Store (Figure 6). We assumed the portion of the bay south of the study area was not used by spawning herring. The bay north of our study area, while extensively used by spawning herring in some years, is closed to the commercial herring egg fishery.

The survey area was divided into six areas, each containing 12 stations, three on each shoreline and six in midbay. A 100 ft transect was established at each station, and the relative abundance of visible vegetation was recorded as abundant, common, sparse, or absent. Divers recorded vegetation type as eelgrass, *Zostera;* surfgrass, *Phyllospadix;* red algae, rhodophyta; green algae, Chlorophyta; or brown algae, Phaeophyta. Other information recorded included time, depth, surface temperature, bottom temperature, water clarity, and type substrate.

Nearshore transects began at water's edge and extended offshore perpendicular to the trend of the immediately adjacent shoreline. Midbay

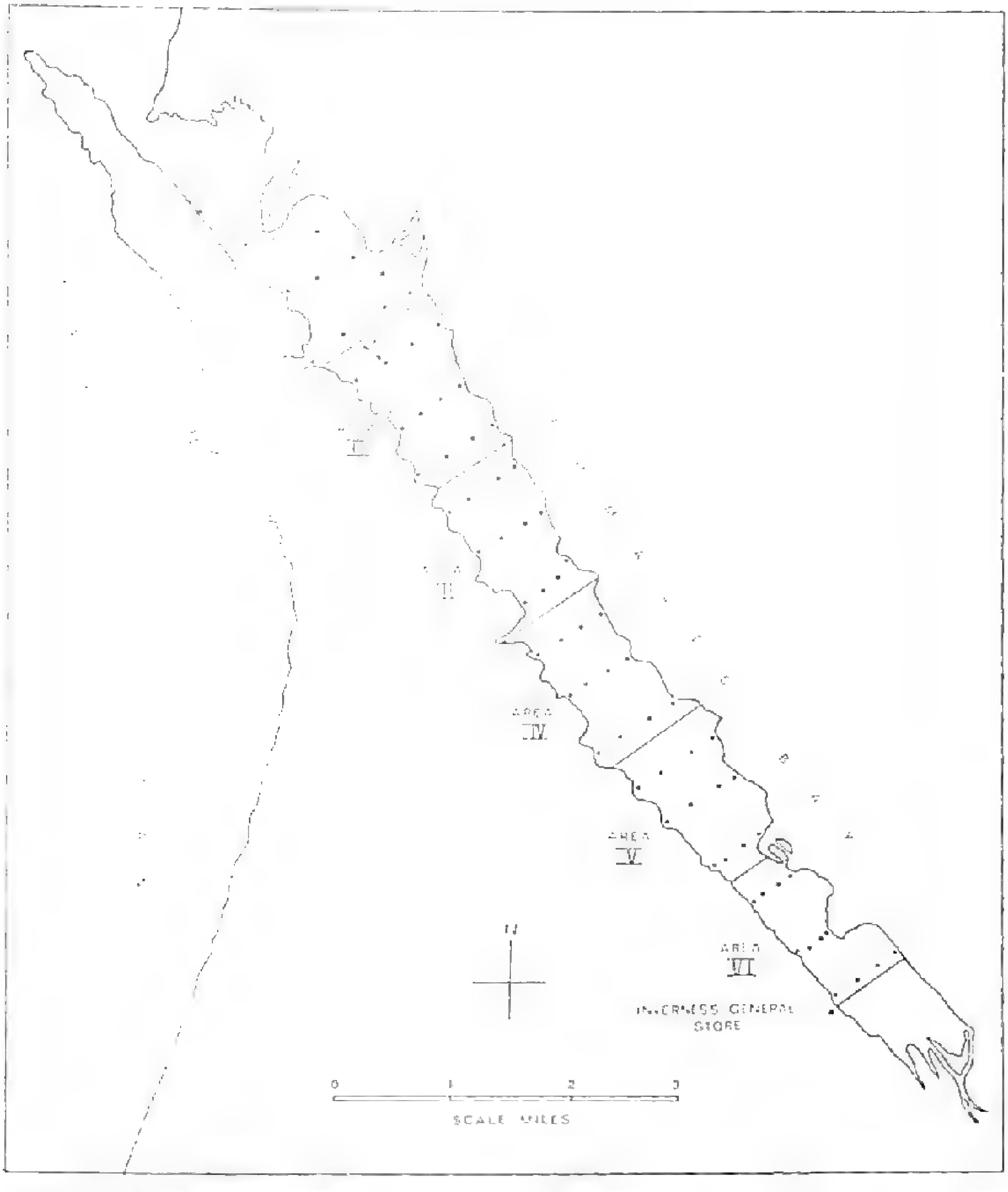


FIGURE 6. Stations for survey of abundance and species composition of Tomales Bay vegetation.

transects were perpendicular to the general shoreline trend. White plastic coated lines, along which divers made their observations, were dropped from the surface to establish transects. Depths at which samples were taken were determined using depth gauges. All depths recorded by divers during the survey were adjusted to mean lower low water level.

Three $\frac{1}{4}$ m^2 quadrats were taken on each transect; one at each end and one in the middle. A wire square, $\frac{1}{2}$ m on a side, was placed so that the white line ran through the middle. Vegetation within the limits of the wire square then was collected and placed in a plastic bag. Vegetation not attached to the bottom was avoided. At stations where

visibility was poor samples were taken by feel and it was often not possible to determine whether or not vegetation was attached to the bottom. At the end of the day, a small amount of 10% buffered formalin was added to each bag. Each sample was washed in freshwater at the laboratory and the plant material sorted to species and identified (Table 7). Plants of each taxon were weighed to the nearest gram.

TABLE 7. Algae Collected from Tomales Bay, California October 7 and 8, 1970

- Division Chlorophyta
  - Order Ulvales
    - Family Ulvaceae
      - *Ulva expansa*
      - *Ulva lobata*
      - *Ulva stenophylla*
      - *Enteromorpha intestinalis*
      - *Enteromorpha clathrata*
      - *Enteromorpha compressa*
      - *Enteromorpha prolifera*
  - Order Cladophorales
    - Family Cladophoraceae
      - *Chaetomorpha aerea*
      - *Cladophora trichotoma*
      - *Cladophora microcladioides*
      - *Rhizoclonium* sp.
      - *Lola lubrica*
- Division Phaeophyta
  - Order Desmarestiales
    - Family Desmarestiaceae
      - *Desmarestia munda*
  - Order Laminariales
    - Family Lessoniaceae
      - *Macrocystis* sp.
  - Order Fucales
    - Family Fucaceae
      - *Fucus distichus*
      - *Pelvetiopsis limitata*
- Division Rhodophyta
  - Order Bangiales
    - Family Bangiaceae
      - *Porphyra perforata*
  - Order Gelidiales
    - Family Gelidiaceae
      - *Gelidium coulteri*
  - Order Cryptonemiales
    - Family Dumontiaceae
      - *Pikea californica*
    - Family Grateloupiaceae
      - *Grateloupia doryphora*
      - *Prionitis lanceolata*
  - Order Gigartinales
    - Family Soleriaceae
      - *Agardhiella coulteri*
    - Family Plocamiaceae
      - *Plocamium coccineum*
    - Family Gracilariaceae
      - *Gracilaria sjoestedtii*
      - *Gracilaria verrucosa*
    - Family Gigartinaceae
      - *Gigartina canaliculata*
      - *Gigartina leptorhynchos*
      - *Gigartina corymbifera*
      - *Gigartina papillata*
      - *Gigartina exasperata*
      - *Rhodoglossum affine*
      - *Iridaea flacida*
  - Order Rhodymeniales
    - Family Rhodymeniaceae
      - *Rhodymenia pacifica*
  - Order Ceramiales
    - Family Ceramiaceae
      - *Spermothamnion snyderae*
      - *Platysiphonia clevelandii*
      - *Ceramium californicum*
    - Family Delesseriaceae
      - *Cryptopleura violacea*
      - *Botryoglossum farlowianum*
    - Family Rhodomelaceae
      - *Polysiphonia pacifica*
      - *Polysiphonia mollis*
      - *Polysiphonia paniculata*

The quadrats from each of the six areas were stratified by water depth in order to facilitate estimating the total plant resource size in the study area. The surface area between depth contours was determined using a polar planimeter and Coast and Geodetic Survey Chart 5603, August 30, 1969, edition. The total weight of each plant taxon in a stratum was estimated by projecting the mean weight sampled per $\frac{1}{4}$ m^2 to the total area within that depth stratum (Table 8).

Results

Only 4% by weight of all vegetation sampled was collected more than 12 ft below the mean lower low water level, even though 24% of all quadrats occurred below that depth. Of the vegetation below 12 ft, 89% occurred in Area II and was primarily eelgrass collected at a single

TABLE 8. **Mean Weight Per Quadrat and Standard Deviations for the Major Vegetation Components of Tomales Bay, California in October 1970**

Area	Depth range (feet)	Total area (m²)	Number quadrats	*Zostera*		*Phyllospadix*		*Gracilaria sjoestedtii*		*Gracilaria verrucosa*		*Ceramiales*		Other *Rhodophyta*		*Phaeophyta*		*Chlorophyta*	
				Grams	SD	Grams	SD	Grams	SD	Grams	SD	Grams	SD	Grams	SD	Grams	SD	Grams	SD
I	†4–6	4,029,000	15	121	342	0	--	0.867	3.09	3.27	11.6	0.133	0.532	T*	--	3.33	12.9	20.1	26.8
	7–12	724,200	7	4.20	12.2	3.71	7.52	4.29	7.68	0	--	4.0	10.6	7.71	17.3	0	--	8.57	17.6
	13–18	571,200	2	0	--	0	--	0	--	0	--	0	--	0	--	0	--	10.5	14.8
	>18	612,000	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
II	†4–6	845,460	16	201	322	0.50	2.0	3.38	13.5	13.7	52.9	0.0625	0.25	5.62	15.8	0	--	8.38	16.9
	7–12	1,263,920	6	308	487	0	--	0	--	0	--	0	--	107	262	0	--	T*	--
	13–18	939,400	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	>18	1,212,680	14	41.4	155	0	--	0	--	0	--	0	--	T*	--	0	--	0.50	1.87
III	†4–6	516,560	15	38.5	123	0	--	3.27	12.4	0.0667	0.258	T*	--	2.27	6.03	0.133	0.516	15.5	40.5
	7–12	333,060	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	13–18	1,477,420	12	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--
	>18	1,221,220	6	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--
IV	†4–6	247,660	18	0	--	0	--	0	--	12.9	31.0	0.611	2.12	0.222	0.943	0	--	1.17	2.96
	7–12	307,440	6	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--
	13–18	1,212,680	10	0	--	0	--	0	--	0	--	0.30	0.675	0	--	0	--	T*	--
	>18	1,989,820	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
V	†4–6	871,080	21	11	50.4	0	--	0	--	3.48	15.9	C†	--	T*	--	0	--	11.6	23.9
	7–12	1,332,240	12	0	--	0	--	0	--	0	--	0.750	2.60	0	--	0	--	0	--
	13–18	1,503,010	3	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--
	>18	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
VI	†4–6	1,639,680	23	0	--	0	--	0	--	0.435	1.56	2.17	6.47	0	--	0.0135	0.208	31.0	93.4
	7–12	1,101,660	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	13–18	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	>18	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

* Not more than ½ gram was found in any quadrat.
† Reported as common along some transects, but not collected in any quadrats.

station. Greater abundance of vegetation at deeper stations in Areas I and II may be the result of better water clarity in these areas. Visibility in the study area varied from 0 at the deepest stations in Areas II, III, IV, V and nearly all of Area VI to 18 to 20 ft at shallower stations in Areas I and II. Visibility at a depth of 6 ft or less in Areas III, IV, and V was 2 to 3 ft.

Eelgrass, a flowering plant, was the most abundant species in the bay. It comprised 75% by weight of all vegetation sampled (Figure 7), and an estimated 4,787 tons occurred in the study area (Table 9). Nearly all eelgrass (99%) occurred in Areas I, II, and III (Figure 8), and 60%

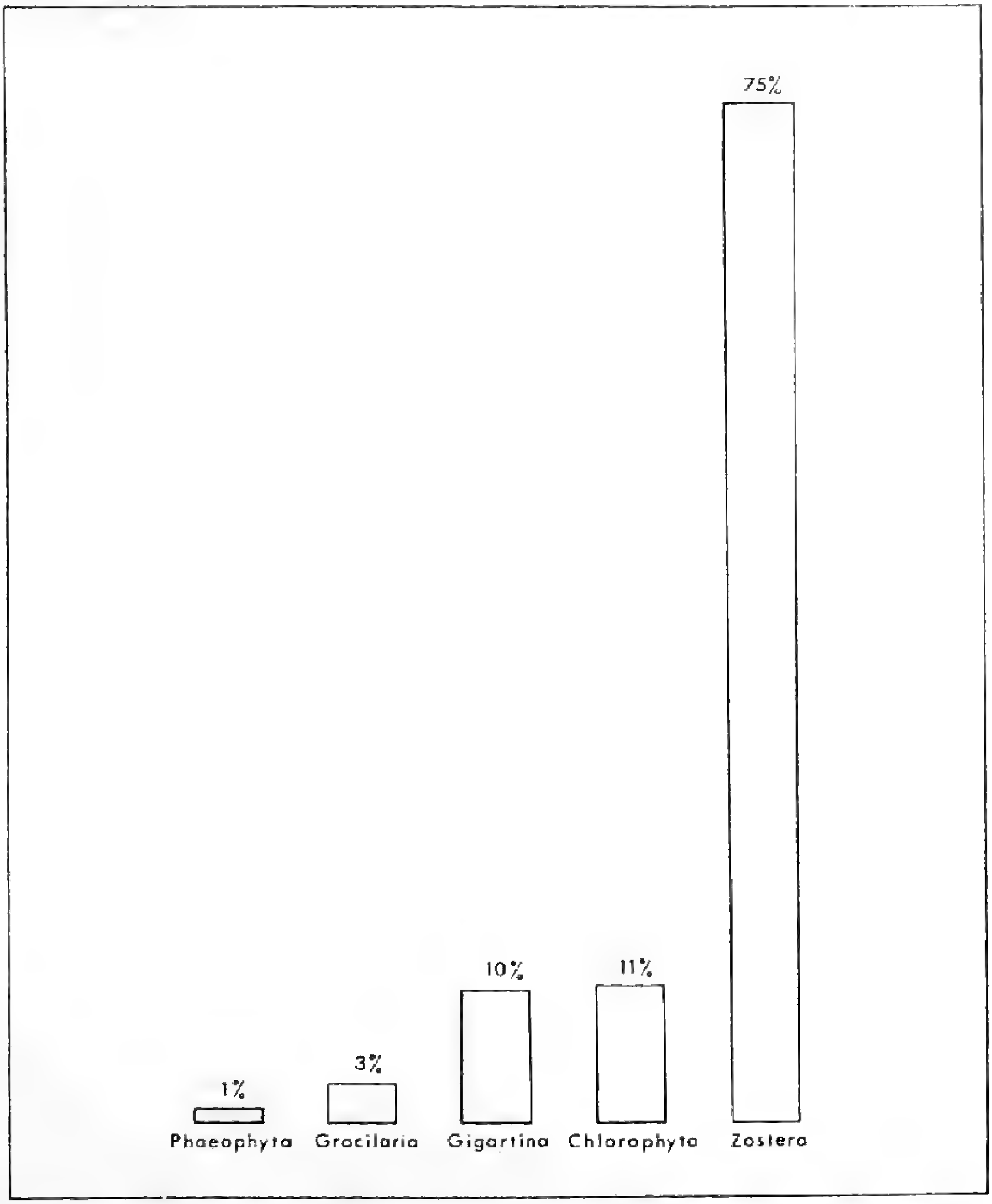


FIGURE 7. The relative abundance of taxa composing 1% or more by wet weight of Tomales Bay vegetation in October 1970.

was collected from less than 6 ft of water. Only 4% was collected below 12 ft. Surfgrass, *Phyllospadix*, the only other flowering plant collected, contributed 0.2% of the vegetation sampled and occurred only in Area I.

FIGURE 8. The distribution of eelgrass, *Zostera marina*, during the fall and winter of 1970–71.

The survey indicates that in October 1970, *Gracilaria sjoestedtii* comprised 50 tons (1%) of the 6,686 tons of vegetation in the study area, and 140 tons (2%) consisted of *Gracilaria verrucosa*. These species are similar in appearance and *G. sjoestedtii* may be synonymized with *G. verrucosa* in the near future. *Gracilaria sjoestedtii* occurred in Areas I, II, and III (Figure 9) and was most abundant in Area I and least in Area III. *G. verrucosa* was found in all areas, with 78% occurring

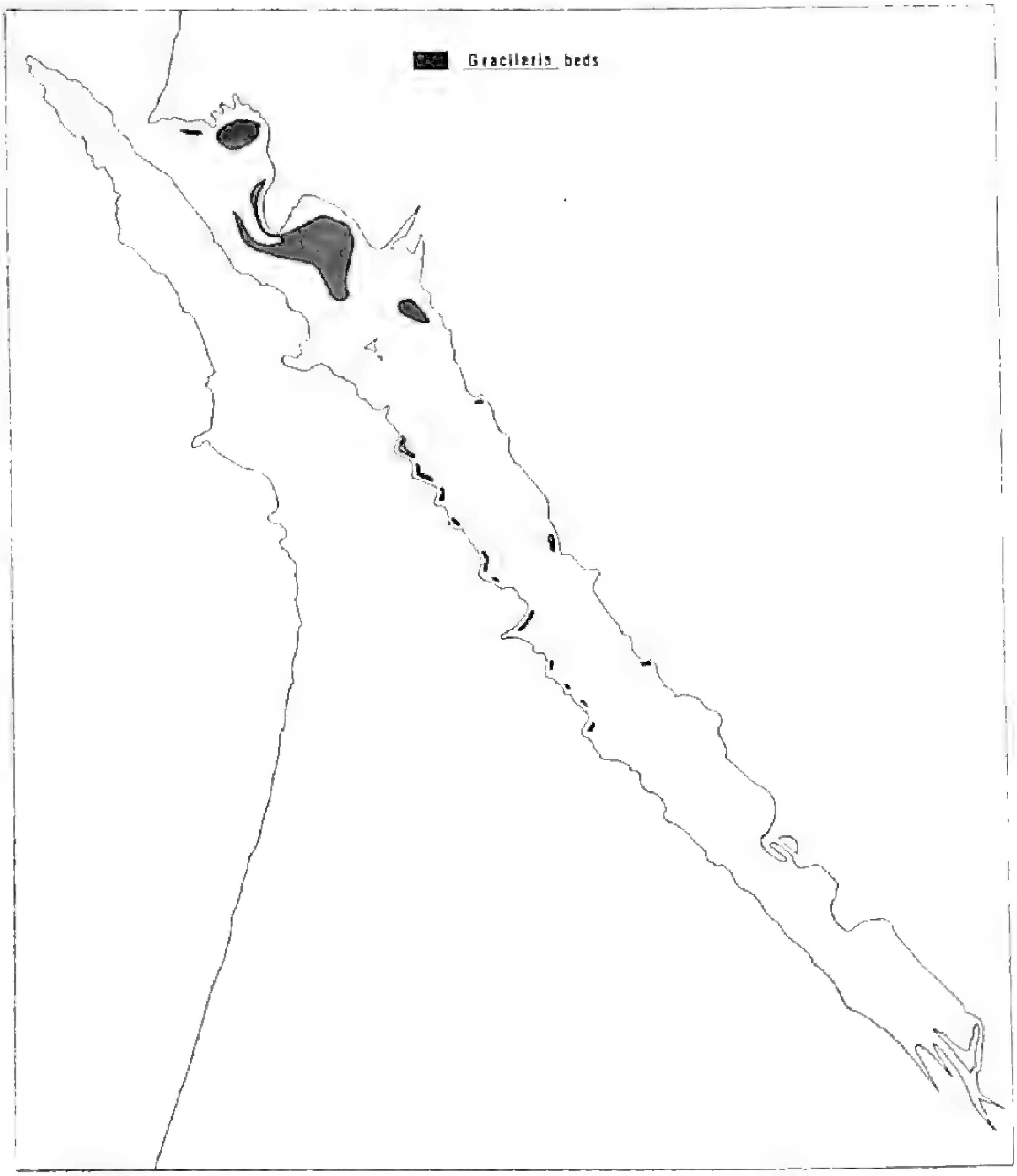


FIGURE 9. The distribution of *Gracilaria* during the fall and winter of 1970–71.

in Areas I and II, and was found at depths of 6 ft or less. All *Gracilaria sjoestedtii* was found less than 12 ft below mean lower low water. At the time of the survey there were long windrows of these two algae along some beaches as a result of storms or strong tides. Not knowing the important contribution they make to the biomass, I avoided sampling plants that were not attached to the bottom. The result being an underestimate of *Gracilaria* biomass.

Both *Gracilaria* species occur attached to the substrate, usually sand bars, as well as in a free floating state. Storms and currents break the *Gracilaria* thallus free from its anchor in the soft substrate. Both the thallus and free floating *Gracilaria* continue to grow (Humm, 1951; Isaac, 1956). Prior to the 1970 vegetation survey, I was not aware of

TABLE 9. Estimated Weights (Tons) of Major Vegetation Components of Tomales Bay in October 1970

Area	Depth range (feet)	*Zostera*	*Phyllospadix*	*Gracilaria sjoestedii*	*Gracilaria verrucosa*	*Ceramiales*	Other *Rhodophyta*	*Phaeophyta*	*Chlorophyta*	Total
I	†4 to 6	2149	0	15	58	2	T*	59	357	2640
	7 to 12	14	12	14	0	13	21	0	27	101
	13 to 18	0	0	0	0	0	0	0	26	26
	>18	--	--	--	--	--	--	--	--	--
	Total	2163	12	29	58	15	21	59	410	2770
II	†4 to 6	751	2	13	51	T*	21	0	31	869
	7 to 12	1717	0	0	0	0	597	0	T*	2314
	13 to 18	--	--	--	--	--	--	--	--	--
	>18	221	0	0	0	0	T*	0	3	224
	Total	2689	2	13	51	T*	618	0	34	3407
III	†4 to 6	93	0	8	T*	T*	6	T*	37	144
	7 to 12	--	--	--	--	--	--	--	--	--
	13 to 18	0	0	0	0	0	0	0	0	0
	>18	0	0	0	0	0	0	0	0	0
	Total	93	0	8	T*	T*	6	T*	37	144
IV	†4 to 6	0	0	0	14	1	T*	0	1	16
	7 to 12	0	0	0	0	0	0	0	0	0
	13 to 18	0	0	0	0	2	0	0	T*	2
	>18	--	--	--	--	--	--	--	--	--
	Total	0	0	0	14	3	0	0	1	18
V	†4 to 6	42	0	0	13	C†	T*	0	45	100
	7 to 12	0	0	0	0	4	0	0	0	4
	13 to 18	0	0	0	0	0	0	0	0	0
	>18	--	--	--	--	--	--	--	--	--
	Total	42	0	0	13	4	0	0	45	104
VI	†4 to 6	0	0	0	3	16	0	T*	224	243
	7 to 12	--	--	--	--	--	--	--	--	--
	13 to 18	--	--	--	--	--	--	--	--	--
	>18	--	--	--	--	--	--	--	--	--
	Total	0	0	0	3	16	0	T*	224	243
Grand Total		4987	14	50	139	38	618	59	751	6686

* Less than ½ ton.
† *Polysiphonia* was reported as common along transects here but not collected in quadrats.

this continued growth and the important contribution it makes to the total biomass of *Gracilaria*. Observations made subsequent to the survey indicate that plants attached to the substrate probably make up a small portion of the total biomass of *Gracilaria*, although drifting plants originated some time, possibly years, in the past from plants fastened to the substrate. Humm (1951) found that while drifting plants constituted the bulk of the *Gracilaria* in the vicinity of Beaufort, North Carolina, they never formed spores of any kind and would never produce plants attached to the substrate therefore unless they themselves became reattached to the substrate in some manner.

Gracilaria that is attached to the substrate is probably limited to the sand bars to the north and west of Toms Pt. along the west shore of the bay south of Pelican Pt. and in the vicinity of Cypress Grove. Large masses of apparently unattached *Gracilaria* gather and grow near the bottom 200 m west of Reynolds and in a channel about 1,100 yards (1 km) NNW of Hog Island. These masses may maintain themselves vegetatively from year to year.

Gracilaria is occasionally found in all eelgrass beds, but particularly in those beds between Toms Pt. and Hog Island and those beds just inside Sand Pt. This is growing and unattached to the substrate, insofar as I have been able to determine, and has been caught in the eelgrass after being transported there by currents. Quantities of *Gracilaria* are washed ashore, particularly during fall. These plants die unless they are washed back into the bay before the center of the mass dries.

While the members of Ceramiales contributed only 0.6% of the vegetation collected, they comprised 16 tons (7%) of the vegetation in Area VI. *Polysiphonia*, a genus in this order, occurred in all six areas; although it forms a significant portion of the vegetation only in Area VI. Red algae (Rhodophyta) other than *Gracilaria* and *Polysiphonia* represented 10% of the vegetation collected in the study area. However, *Gigartina* collected in a single sample in Area II accounted for 95% of this weight. Many other genera of red algae, Division Rhodophyta, were collected but none was present in any sizable quantity.

The brown algae (Phaeophyta) were represented by plants in the general *Fucus*, *Pelvetiopsis*, and *Macrocystis*. *Pelvetiopsis* and *Fucus* occurred in Area I, and *Macrocystis* was recorded from Area III. Only 0.9% of the material collected was brown algae.

Since this survey was conducted, the biomass of *Macrocystis pyrifera* has increased many fold. No beds of kelp were noted during the vegetation survey. Small beds were seen during the 1971 herring spawning survey and more extensive beds were present during the 1972 spawning survey.

Green algae (Chlorophyta) contributed 11% of the vegetation collected. Filamentous green algae occurred most abundantly in Areas I and VI, which was due undoubtedly to the large muddy tidal flats in these areas. Chlorophyta with broader thalli occurred almost entirely in Areas I and II, probably due to the better water clarity in these areas.

Gracilaria Harvesting

A continued supply of *Gracilaria* is essential to a viable herring egg-on-seaweed fishery. The harvest of *Gracilaria verrucosa* from the

vicinity of Beaufort, North Carolina, during World War II and the years immediately following (Humm, 1951) may provide some lessons in the management of harvesting these plants. There was no noticeable decrease in the quantity of *G. verrucosa* during 1943 and 1944 when 750 and 2,070 wet tons, respectively, were harvested. Heavy harvesting during January, February, and March 1945, when the standing crop of *G. verrucosa* was at a naturally low level of abundance, may account for the lower landings of 900 and 150 wet tons during 1945 and 1946 respectively, which took a noticeably large portion of the standing crop.

Gracilaria verrucosa was harvested in New South Wales during the same time period, and in spite of a take of 1,750 tons in 1943 there was no reported depletion of the resource. In fact, the following year the crop was heavier in one of the three bays harvested and the reason given for the decline in the other two bays was a storm carried much of the *G. verrucosa* away from the beds just before the crop matured (Wood, 1945). In none of the above mentioned *Gracilaria* harvesting operations were there any regulations restricting the amount of *Gracilaria* that could be harvested. The entire biomass could be taken at any time.

To provide some control, Humm (1951) suggested that collecting of *Gracilaria* along the Atlantic coast of the United States be prohibited from the time plant growth stops in fall or winter (January 1 in North Carolina) until growth is well underway in spring (probably about May 1). This prohibition was suggested in order to insure "seed material" for the next year's crop. He suggested when conditions became favorable for this "seed material", it would increase 100 fold within 1 or 2 months. Had the take been restricted to a small percentage of the total biomass, harvesting would have been permissible in any month.

RECOMMENDATIONS

A minimum of 163 tons of herring eggs are spawned annually in Tomales Bay. These eggs are subject to heavy predation for 3 days after spawning and this predation is most intensive where eggs are most abundant. Herring eggs must be harvested within a few days of spawning or they lose their market value. A harvest of 10% of the eggs spawned (16 tons) would not significantly reduce the number of eggs that hatch. The harvest would displace predation by other organisms rather than adding to such predation, since the rate of predation declines as egg abundance declines. No organisms have been reported to be dependent upon herring eggs for food during any phase of their life history, although Yocom and Keller (1961) reported the black sea brant's, *Branta nigricans*, dependence upon eelgrass.

High quality herring eggs-on-seaweed must consist of about 80% eggs by weight. A 20 ton harvest of herring eggs-on-seaweed would consist of 4 tons of *Gracilaria* or approximately 2% of the *Gracilaria* estimated to be in the bay in October 1970. This rate of harvest will not deplete the Tomales Bay *Gracilaria* resource.

Should the harvest of whole herring from Tomales ever again exceed 500 tons annually, it may be necessary to reduce the allowable harvest of herring eggs-on-seaweed.

ACKNOWLEDGMENTS

Planning of the vegetation survey was initiated by the late Charles H. Turner, California Department of Fish and Game. Alec R. Strachan, formerly with California Department of Fish and Game, implemented the survey itself. Algae were identified by Isabella A. Abbott, Hopkins Marine Station, Stanford University. Department wardens and divers, too numerous to mention, freely gave of their time to assist in the survey, though it in no way promoted the goals of their own projects and responsibilities.

Herbert W. Frey, California Department of Fish and Game, critically reviewed the manuscript and offered many helpful suggestions. Kenneth Sato and Warren Nobusada, Consolidated Factors, Monterey, kindly provided assistance in determining the sex ratio of herring, and Gregory D. Briggs and Charles S. Versaggi developed methods and counted eggs for estimates of herring fecundity and number of eggs spawned.

SUMMARY

1) The Tomales Bay herring catch exceeded 1,000 tons from 1916 to 1919, and 1951 to 1953, and 500 tons in 1948 and from 1958 to 1960 without any noticeable decline in the abundance of herring.

2) Pacific herring spawn in the shallows of Tomales Bay from late December through early March.

3) About 103 million eggs are produced by a ton of spawning herring and a billion eggs weigh about 1 ton.

4) A minimum of 163 billion eggs are spawned annually.

5) Predation rates on herring eggs range between 56 and 99%, with birds accounting for the major portion of this predation. Approximately 66% of predation occurs within 3 days of spawning.

6) There are in excess of 1,600 tons of herring spawning in Tomales Bay.

7) Eelgrass comprises 75% of all vegetation in Tomales Bay.

8) *Gracilaria,* the seaweed harvested with herring eggs, occurs in two conditions: attached to the substrate, usually a soft bottom, or as drifting plants torn from attached plants.

9) The bulk of the biomass is comprised of drifting plants which continue to grow.

10) There were 190 tons, 3% of all vegetation in the bay, of *Gracilaria* in Tomales Bay in October 1970. This is probably a minimum estimate since storms had washed large volumes of *Gracilaria* upon the beaches immediately prior to the survey.

11) *Gracilaria* is capable of increasing its biomass 100 fold per month in the summer; however, it decays during the winter.

12) A harvest of not more than 20 tons of herring eggs-on-seaweed in Tomales Bay is recommended.

13) If herring harvest in Tomales Bay exceeds 500 tons annually, then it may be necessary to reduce the allowable harvest of herring eggs-on-seaweed.

REFERENCES

Daetwyler, Calvin C., 1966. Marine geology of Tomales Bay, central California. U. of Pacific, Pac. Mar. Sta. Res. Rep. (6) :1–169.

Hart, John Lawson, and Albert L. Tester. 1934. Quantitative studies on herring spawning. Trans. Am. Fish. Soc. 64 : 307–312.

Hourston, A. S. 1953. Estimation of herring population size by means of echo-sounder tracings and its application to herring research. Fish. Res. Bd. Canada, Circ. (26) :1–18.

Hughes, Eldon P. 1949. Pacific herring, p. 101, 102. *In* Bureau of Marine Fisheries. The commercial fish catch of California for the year 1947 with an historical review: 1916–1947. Calif. Div. Fish and Game, Fish Bull. (74) :1–267.

Humm, Harold J. 1951. The seaweed resources of North Carolina, p. 231–250. *In* Harden F. Taylor. Survey of the marine fisheries of North Carolina. U. of N.C. Press, Chapel Hill. 555 p.

Isaac, Wm. Edwyn. 1959. The ecology of *Gracilaria confervoides* (L.) Grev. in South Africa with special reference to its ecology in the Saldanha-Langebaan lagoon, p. 173–185. *In* Second international seaweed symposium. Permagon Press, London and New York. 220 p.

Johnson, R. G., W. R. Bryant and J. W. Hedgpeth. 1961. Ecological survey of Tomales Bay, preliminary report of the 1960 hydrographic survey. U. of Pacific, Pacific Mar. Sta., Res. Rep. (1) :1–19.

Miller, Daniel J., and John Schmidtke. 1956. Report on the distribution and abundance of Pacific herring (*Clupea pallasi*) along the coast of central and southern California. Calif. Fish Game 42(3) :163–187.

Outram, D. N. 1958. Seagulls biggest killers of herring spawn. Western Fisheries 57(1) :38–42.

Rounsefell, George A. 1930. Contribution to the biology of the Pacific herring, *Clupea pallasii*, and the condition of the fishery in Alaska. U. S. Bur. Fish., Bull. 45 :227–320.

Scofield, W. L. 1952. The Tomales Bay herring fishery. Calif. Fish Game 38(4) :499–504.

Shohara, James H. 1972. Japan to decontrol herring roe imports. U. S. Dep. Commerce, Nat. Mar. Fish. Serv., Foreign Fishery Information Release, 72(14) :3.

Stevenson, J. C. 1955. The movement of herring in British Columbia waters as described by tagging with a description tagging and tag recovery methods. Rapp. et Proc.—Verb., Conc. Expl. Mer. 140(2) :33–34.

Wood, E. J. Ferguson. 1945. The sources of algae in Australia, J. Coun. Sci. Ind. Res., Australia 18 :263–273.

Yocom, Charles F., and Mathew Keller. 1961. Correlation of food habits and abundance of waterfowl, Humboldt Bay, California. Calif. Fish Game 47(1) : 41–53.

Calif. Fish and Game, 59(1): 62–72. 1973.

PARTYBOAT LOGS SHOW HOW SKIN AND SCUBA DIVERS FARED—1965 THROUGH 1970[1]

PARKE H. YOUNG
Marine Resources Region
California Department of Fish and Game

Diving logs obtained from California partyboats over the period 1965–1970 show 83,996 divers landed 199,466 fish (fish, mollusks, and crustaceans), averaging 2.4 fish per diver. Abalones, spiny lobster, rock scallop, California sheephead and kelp bass, in order, dominated the 6 years' catch. Southern California offshore islands were most favored by divers. Santa Catalina and Santa Cruz islands supported the bulk of diving effort.

INTRODUCTION

This report summarizes the diving activities of a growing group of California skin and scuba divers for the 6 year period 1965–1970. The data were derived from logs maintained by the skippers of a small fleet of diving boats operating for hire, (Figures 1 and 2). California law (Fish and Game Code) requires the skippers of sportfishing (diving) boats operating under hire to keep logs of the catch, diving effort, area of operation, and other information as directed by the California Fish and Game Commission. With the exception of a few incomplete or illegible logs, all diving data received by the Department of Fish and Game for 1965–1970 are included in the accompanying tables.

LOGBOOK DATA

During the 1965–1970 period, 3,873 usable logs were received, and these revealed that 83,996 divers landed 199,466 fish (fish, mollusks, and crustaceans), an overall average of 2.4 fish per diver day. On average, each diving boat carried 22 divers and fished for 5 hr per trip, approximately the same time expended by partyboat anglers. Actually, an individual rarely will dive for 5 hr, although the boat may be anchored for that period of time.

The number of boats in the southern California diving fleet increased, and more trips were conducted per boat each year as the 6 year period progressed, (Table 1). Off central California, partyboat diving operations are very limited. Abalones are the chief target of central California divers (Table 2).

Southern California divers boated many species of fish, extending diving activity over a wide area, particularly around the offshore islands (Tables 3–8). Santa Catalina Island was, by far, the most visited area, although diving success was not outstanding; it is more important as a training ground than a preferred location for serious diving.

[1] Submitted for publication July 1972.

TABLE 1. California Partyboat Diving Fleet 1965–1970
Number of Boats Reporting and Trip Frequency

Year	Number of boats	Number of trips per boat, average	Year	Number of boats	Number of trips per boat, average
1965	13	30	1968	17	40
1966	21	23	1969	19	41
1967	17	30	1970	21	43

FIGURE 1. A large southern California partyboat adapted to the needs of the diver. Compressed air is available to refill scuba tanks; an air pressure gauge is visible approximately amidships on the engine housing. A live bait tank appears forward of the housing. *Photograph by Jack W. Schott.*

TABLE 2. Diver Catch and Effort Central California 1965–1970

Common name	1965	1966	1967	1968	1969	1970	Total
Abalone*	----	23	none	none	17	15	55
Rockfish*	----	5	----	----	9	----	14
Lingcod	----	1	reported	reported	5	----	6
Cabezon	----	1	----	----	----	----	1
Flatfish	3	----	----	----	----	----	3
Wolf eel	----	----	----	----	1	----	1
Total	3	30	----	----	32	15	80
Number of trips	1	1	----	----	1	1	4
Number of divers	9	17	----	----	9	5	40
No. of diver hours	58.5	85.0	----	----	27.0	20.0	190.5
Catch/diver	.3	1.8	----	----	3.6	3.0	2.0
Catch/diver hour	----	.35	----	----	1.2	.75	

* Probably more than one kind.

FIGURE 2. The open low stern and the wide steel mesh landing screen below the surface makes access to this vessel and to the water relatively convenient. Scuba tanks are refilled from the installation in the center of the deck. *Photograph by Jack W. Schott.*

Southern California catch records indicate there is more interest in shellfish than finfish (Table 9). From 1965 through 1970, 54 to 59% of the diver bag was abalones, in spite of a closed season from mid-January to mid-March. Spiny lobsters made up 12 to 17% of the catch, although the closed season, mid-March through September, must have limited the catch considerably. Rock scallops, an unimportant species prior to 1963, ranked third in take, comprising 10 to 15% of the total catch. Sheephead, the most important finfish, constituted 8 to 9%, kelp bass 4 to 6%. Size (total length) and bag limits impede hook and line anglers for finfish, but the diver is probably not much troubled by these limitations, except in the areas where kelp bass provide an important part of the take. On the perimeters of the southern California islands, where most partyboat diving takes place, divers taking abalones could increase their catch substantially if it were not for bag (five abalones) and size limits. The abalone population along the mainland shore may not be great enough to provide more than a modest catch, with or without bag and size limits. Although no more than seven spiny lobsters ($3\frac{1}{4}$ inches eye socket to rear edge of body shell) may be possessed, relatively few divers have the opportunity or are skilled enough to be cramped by these regulations.

Three species are relatively vulnerable to divers and these could be overexploited. Although the giant sea bass is seldom taken by partyboat divers, according to all reports, it is available to the skilled diver with capable gear. Effective March 1, 1971 angling and diving regulations were amended to allow possession of one bass (instead of two), and it was made illegal to spear them, during June and July. Sheephead, particularly very old and large specimens, are often said to be too easy a target and, therefore, subject to depletion locally. So far, a wait-and-see attitude prevails. The scallop shows evidence of a decrease in abundance, but only in one important locality. Almost 60% of all scallops taken during the 6 year period were from Santa Cruz Island. The number of divers working Santa Cruz Island more than doubled, whereas the scallop catch increased only slightly, failing to keep pace with diver pressure.

REFERENCES

Wood, William F. 1964. Partyboat logs show how skindivers fared during 1960, 1961, and 1962. Calif. Fish Game 50(2):114–117.

———. 1967. Partyboat logs show how skindivers fared during 1963 and 1964. Calif. Fish Game 53(3):192–196.

Young, Parke H. 1961. Partyboat logs show how skindivers fared during 1958 and 1959. Calif. Fish Game 47(3):303–305.

TABLE 3. Marine Species Catch and Effort Selected Diving Areas, Southern California, 1965

Common name	Santa Catalina Island	Santa Cruz Island	Santa Rosa Island	Anacapa Island	Santa Barbara Island	San Clemente Island	San Nicolas Island	Los Coronados Island	Bishop Rock	Newport Beach	Total
Abalone*	7,442	3,075	386	1,276	577	92	98	--	50	--	12,996
Spiny lobster	611	1,064	1,020	173	781	103	190	--	150	--	4,092
Scallop, rock	90	2,110	295	617	4	--	--	--	--	--	3,116
Calif. sheephead	711	779	37	252	178	--	15	12	12	--	1,996
Kelp bass	660	168	15	60	65	--	10	--	--	--	978
Rockfish*	3	197	--	92	--	--	--	--	--	--	292
Perch*	257	18	--	4	8	--	--	--	--	--	287
Halfmoon	141	--	--	--	--	--	--	--	--	--	141
Calif. halibut	64	23	--	2	4	--	--	--	--	--	93
Cabezon	22	3	3	4	1	--	--	--	--	--	33
Lingcod	--	10	10	1	1	--	--	--	--	--	22
Pacific mackerel	19	--	--	--	--	--	--	--	--	--	19
Pacific bonito	7	3	--	3	--	--	--	--	--	--	13
Spider crab	5	--	--	--	--	--	--	--	--	3	8
Opaleye	--	7	--	--	--	--	--	--	--	--	7
Flatfish	2	1	--	3	--	--	--	--	--	--	6
White seabass	6	--	--	--	--	--	--	--	--	--	6
Sargo	4	--	--	--	--	--	--	--	--	--	4
Sculpin	1	--	--	2	--	--	--	--	--	--	3
Swordfish	--	1	--	--	--	--	--	--	--	--	1
Miscellaneous	--	5	--	--	--	--	--	--	--	--	5
Total	10,015	7,464	1,766	2,519	1,619	195	313	12	212	3	24,118
No. of trips	237	88	13	32	20	1	1	1	1	1	395
No. of divers	4,325	1,821	230	581	386	23	30	20	30	8	7,454
No. of diver-hours	22,153.0	10,260.5	1,151.5	3,798.5	1,876.0	46.0	390.0	100.0	360.0	32.0	40,170.5
Catch/diver	2.3	4.1	7.7	4.3	4.2	8.5	10.4	.6	7.1	.4	3.2
Catch/diver-hour	.45	.73	1.53	.66	.86	4.24	.80	.12	.59	.09	.60

* Probably more than one kind.

TABLE 4. Marine Species Catch and Effort Selected Diving Areas, Southern California, 1966

Common name	Santa Catalina Island	Santa Cruz Island	Santa Rosa Island	Anacapa Island	Santa Barbara Island	San Clemente Island	San Nicolas Island	Los Coronados Island	San Miguel Island	Newport Beach	Total
Abalone*	11,466	3,095	150	594	515	278	171	--	28	97	16,394
Scallop, rock	469	2,107	537	285	61	16	18	--	42	276	4,201
Spiny lobster	528	946	1,188	79	426	--	368	--	--	--	3,535
Calif. sheephead	892	833	141	208	133	124	31	--	12	15	2,389
Kelp bass	692	576	28	169	33	101	20	--	5	14	1,638
Perch*	438	13	--	3	15	--	--	--	--	--	469
Rockfish*	4	117	27	93	--	--	--	--	--	--	271
Calif. halibut	74	47	1	8	--	--	--	--	--	2	132
Lingcod	1	19	45	1	--	--	--	--	1	--	67
Halfmoon	51	--	--	--	--	--	--	--	--	--	51
Cabezon	34	12	1	--	1	--	--	--	--	--	48
Sculpin	27	11	--	3	--	--	--	--	--	--	41
Opaleye	2	25	--	--	--	4	--	--	--	2	33
White seabass	3	1	--	11	--	--	--	--	--	--	15
Flatfish	2	5	--	--	--	--	--	--	--	--	7
Pacific mackerel	6	--	--	--	--	--	--	--	--	--	6
Ocean whitefish	3	--	--	--	--	1	--	--	--	--	4
Yellowfin croaker	3	--	--	--	--	--	--	--	--	--	3
Calif. yellowtail	--	--	--	--	--	--	--	1	--	--	1
Calif. barracuda	--	--	--	--	--	1	--	--	--	--	1
Miscellaneous	35	11	--	9	--	--	--	--	--	--	55
Total	14,733	8,238	2,118	1,463	1,184	525	608	1	88	406	29,361
No. of trips	314	92	10	17	16	6	4	1	1	13	480
No. of divers	6,082	1,731	350	307	354	152	101	15	20	169	9,281
No. of diver-hours	30,083.5	8,911.8	1,635.0	1,619.5	2,018.0	830.0	819.0	30.0	50.0	812.5	46,839.3
Catch/diver	2.4	4.8	6.1	4.8	3.3	3.5	6.0	--	4.4	2.4	3.2
Catch/diver-hour	.49	.92	1.30	.90	.59	.63	.72	--	1.76	.50	.63

* Probably more than one kind.

TABLE 5. **Marine Species Catch and Effort Selected Diving Areas, Southern California, 1967**

Common name	Santa Catalina Island	Santa Cruz Island	Santa Rosa Island	Anacapa Island	Santa Barbara Island	San Clemente Island	San Nicolas Island	San Miguel Island	Bishop Rock	Newport Beach	Total
Abalone*	10,486	3,132	215	1,332	359	349	13	150	10	15	16,061
Spiny lobster	730	990	1,444	201	319	146	93	--	388	14	4,325
Scallop, rock	240	2,178	441	335	7	15	19	112	--	20	3,387
Calif. sheephead	898	862	111	237	159	91	10	42	2	--	2,415
Kelp bass	696	550	47	67	69	144	18	37	1	3	1,632
Perch*	179	22	--	3	11	--	6	--	--	--	221
Calif. halibut	45	64	16	15	--	3	--	13	--	--	156
Rockfish*	12	38	17	42	--	--	2	8	--	--	119
Lingcod	--	15	30	--	--	--	--	7	--	--	52
Halfmoon	45	--	--	--	--	--	--	--	--	--	45
Flatfish	30	--	--	3	--	--	--	--	--	--	33
Sculpin	2	20	3	1	--	--	--	3	--	--	29
Opaleye	23	--	--	--	--	--	--	--	--	--	23
Jack mackerel	20	--	--	--	--	--	--	--	--	--	20
Cabezon	6	11	--	--	--	--	1	--	--	--	18
White seabass	2	--	--	--	--	1	--	--	--	--	3
Moray	2	--	--	--	--	--	--	--	--	--	2
Calif. yellowtail	1	--	--	--	--	--	--	--	--	--	1
Miscellaneous	3	--	--	--	--	--	--	--	--	--	3
Total	13,420	7,882	2,324	2,256	924	752	162	372	401	52	28,545
No. of trips	335	87	21	32	13	10	3	3	3	2	509
No. of divers	6,737	1,032	465	581	317	244	62	64	80	22	10,507
No. of diver-hours	28,686.0	10,182.0	1,951.5	3,395.0	1,551.0	1,305.0	758.0	340.0	785.0	101.0	49,057.5
Catch/diver	2.0	4.1	5.0	3.9	2.9	3.1	2.6	5.8	5.0	2.4	2.7
Catch/diver-hour	.47	.77	1.19	.66	.59	.58	.21	1.09	.51	.51	.58

* Probably more than one kind.

TABLE 6. Marine Species Catch and Effort Selected Diving Areas, Southern California, 1968

Common name	Santa Catalina Island	Santa Cruz Island	Santa Rosa Island	Anacapa Island	Santa Barbara Island	San Clemente Island	San Nicolas Island	Los Coronados Island	Bishop Rock	Total
Abalone*	12,076	1,677	665	1,690	987	702	117	--	142	21,056
Spiny lobster	583	317	2,118	26	277	132	295	--	552	4,600
Scallop, rock	1,599	1,654	389	161	30	--	26	--	3	4,362
Calif. sheephead	1,245	817	110	311	249	293	70	79	--	3,111
Kelp bass	893	460	79	65	190	98	18	--	--	1,812
Rockfish*	36	19	--	74	63	--	11	--	--	233
Perch*	170	7	--	32	--	--	--	--	--	209
Calif. halibut	43	38	--	4	1	1	--	--	--	87
Opaleye	25	--	--	7	--	--	--	7	--	39
Lingcod	4	20	11	2	--	--	--	--	--	37
Flatfish	12	10	--	10	--	--	--	--	--	32
Cabezon	16	3	--	7	--	1	--	--	--	27
Sculpin	3	19	1	--	--	--	--	--	--	23
Halfmoon	7	--	--	--	--	--	--	--	--	7
Giant sea bass	--	5	--	--	1	--	--	--	--	6
Pacific mackerel	5	--	--	--	--	--	--	--	--	5
White seabass	--	2	--	1	--	1	--	--	--	4
Calif. yellowtail	2	--	--	--	--	--	--	--	--	2
Sargo	2	--	--	--	--	--	--	--	--	2
Moray	1	--	--	--	--	--	--	--	--	1
Miscellaneous	39	13	--	--	60	1	--	--	12	125
Total	16,761	8,091	3,673	2,953	1,867	1,139	534	86	700	35,813
No. of trips	407	124	45	42	24	16	5	3	6	672
No. of divers	9,235	2,558	1,018	872	624	351	85	61	130	14,934
No. diver-hours	41,136.7	12,902.0	5,182.5	4,665.0	3,121.0	1,847.2	604.5	326.0	1,210.5	71,205.4
Catch/diver	1.8	3.2	3.6	3.4	3.0	3.2	6.3	1.4	5.5	2.4
Catch/diver-hour	.40	.63	.71	.63	.60	.62	.88	.26	.59	.50

* Probably more than one kind.

TABLE 7. **Marine Species Catch and Effort Selected Diving Areas, Southern California, 1969**

Common name	Santa Catalina Island	Santa Cruz Island	Santa Rosa Island	Anacapa Island	Santa Barbara Island	San Clemente Island	San Nicolas Island	San Miguel Island	Bishop Rock	Newport Beach	Total
Abalone*	12,205	4,875	585	1,518	1,300	713	760	246	50	--	22,291
Spiny lobster	750	1,090	2,510	73	516	175	614	--	248	--	6,006
Scallop, rock	825	2,760	218	248	58	33	110	109	--	253	4,614
Calif. sheephead	819	1,121	110	329	383	96	167	21	20	27	3,093
Kelp bass	682	555	72	95	125	258	42	20	5	18	1,872
Rockfish*	45	103	12	--	65	--	3	16	--	--	244
Calif. halibut	68	57	5	--	3	--	2	6	--	24	165
Perch*	9	83	--	--	--	--	--	--	--	--	92
Sculpin	27	4	--	--	--	3	--	--	--	--	34
Flatfish	2	17	--	--	--	--	--	--	--	--	19
Cabezon	11	6	--	--	--	--	--	1	1	--	19
Lingcod	4	4	6	--	--	--	--	3	--	--	17
Halfmoon	16	--	--	--	--	--	--	--	--	--	16
Calif. yellowtail	1	--	--	--	--	8	--	--	--	--	9
Moray	5	--	--	--	--	--	--	--	--	--	5
White seabass	--	2	--	--	--	--	--	--	--	--	2
Opaleye	--	2	--	--	--	--	--	--	--	--	2
Calif. barracuda	1	--	--	--	--	--	--	--	--	--	1
Miscellaneous	6	1	--	--	--	--	--	--	--	--	7
Total	15,476	10,680	3,518	2,293	2,480	1,286	1,707	422	324	322	38,508
No. of trips	449	156	50	35	21	20	16	5	2	9	763
No. of divers	10,880	3,338	1,096	801	544	437	352	89	62	94	17,693
No. diver-hours	52,884.7	16,958.0	4,926.5	4,956.0	2,961.5	1,834.8	1,905.5	407.0	558.0	427.5	87,819.5
Catch/diver	1.4	3.2	3.2	2.9	4.6	2.9	4.8	4.7	5.2	3.4	2.2
Catch/diver-hour	.29	.63	.71	.46	.84	.70	.90	1.03	.58	.75	.44

* Probably more than one kind.

TABLE 8. Marine Species Catch and Effort Selected Diving Areas, Southern California, 1970

Common name	Santa Catalina Island	Santa Cruz Island	Santa Rosa Island	Anacapa Island	Santa Barbara Island	San Clemente Island	San Nicolas Island	Los Coronados Island	San Miguel Island	Bishop Rock	Total
Abalone*	14,780	5,278	1,130	1,221	338	680	635	--	297	35	24,394
Spiny lobster	763	867	1,873	112	100	155	1,503	--	--	494	5,897
Scallop, rock	743	2,510	468	311	30	33	4	--	108	--	4,246
Calif. sheephead	889	1,240	252	259	48	180	123	288	35	--	3,314
Kelp bass	1,211	728	315	50	25	169	50	11	77	--	2,636
Rockfish*	20	270	343	55	--	--	--	6	179	--	873
Calif. halibut	86	28	5	1	1	1	1	11	12	--	146
Lingcod	5	28	40	--	--	--	--	--	13	--	86
Sculpin	33	11	--	1	--	--	--	32	--	--	77
Perch*	12	22	--	36	--	--	--	--	--	--	70
Cabezon	49	2	--	3	--	6	4	2	1	--	67
Pacific mackerel	13	--	--	10	--	--	--	3	--	--	26
Pacific bonito	3	14	--	--	--	--	--	--	--	--	17
Calif. yellowtail	7	--	--	--	--	2	--	4	--	--	13
Flatfish	9	--	--	--	--	--	--	--	--	--	9
Giant sea bass	1	--	--	--	--	1	1	1	1	--	5
Opaleye	2	3	--	--	--	--	--	--	--	--	5
White seabass	1	--	--	--	--	1	--	2	--	--	4
Ocean whitefish	--	--	--	--	--	--	1	--	--	--	1
Miscellaneous	7	8	--	4	4	--	--	--	--	--	23
Total	18,634	11,048	4,426	2,093	546	1,228	2,322	360	723	529	41,909
No. of trips	615	193	67	46	9	23	17	41	9	6	1,029
No. of divers	14,751	3,925	1,459	723	217	497	382	1,359	212	105	23,630
No. diver-hours	74,376.9	17,929.5	6,898.5	3,189.5	1,036.5	2,801.0	2,197.0	6,491.0	822.0	780.0	116,524.9
Catch/diver	1.3	2.8	3.0	2.9	2.5	2.5	6.1	.3	3.4	5.0	1.8
Catch/diver-hour	.25	.62	.64	.66	.53	.44	1.06	.06	.88	.68	.36

* Probably more than one kind.

TABLE 9. Marine Species Taken by Charter Divers off Southern California, 1965–1970

Common name	Number reported					
	1965	1966	1967	1968	1969	1970
Abalone*	12,996	16,414	16,173	21,091	22,431	21,416
Spiny lobster	4,092	3,543	4,393	4,071	6,051	5,933
Scallop, rock	3,146	4,300	3,446	4,386	4,664	4,246
California sheephead	2,001	2,403	2,415	3,116	3,123	3,314
Kelp and sand bass	978	1,641	1,633	1,846	1,888	2,641
Rockfish*	292	271	119	233	251	873
Perch*	287	469	230	209	92	70
Halfmoon	141	54	45	7	16	--
California halibut	93	133	157	87	167	146
Cabezon	33	48	18	27	25	67
Lingcod	22	67	52	38	18	86
Pacific mackerel	19	6	--	5	--	26
Pacific bonito	13	--	--	--	--	17
Opaleye	7	33	23	39	2	5
Flatfish	6	8	33	32	19	10
White seabass	6	15	3	4	2	4
Yellowtail	--	1	1	2	9	13
Giant sea bass	--	--	--	6	--	5
Barracuda	--	1	--	--	1	--
Swordfish	1	--	--	--	--	
Sculpin	3	41	29	23	34	77
Misc. fish	17	61	25	124	12	23
Total	24,156	29,512	28,795	35,916	38,808	41,975
Number of trips	396	487	513	672	770	1,031
Number of divers	7,478	9,362	10,571	14,934	17,836	23,656
Number of diver-hours	40,266.5	46,754.3	49,316.5	71,295.4	88,617.5	116,587.9
Catch/diver	3.2	3.2	2.7	2.4	2.2	1.8
Catch/diver-hour	.60	.63	.58	.50	.44	.36

* Probably more than one kind.

TABLE 10. Common and Scientific Names of Marine Species Taken by Partyboat Divers in California, 1965–1970

Common name	Scientific name	Common name	Scientific name
		Fishes	
Barracuda, California	*Sphyraena argentea*	Ocean whitefish	*Caulolatilus princeps*
Bass, giant sea	*Stereolepis gigas*	Opaleye	*Girella nigricans*
Bass, kelp	*Paralabrax clathratus*	Perch*	Species of embiotocids
Bonito, Pacific	*Sarda chiliensis*	Rockfish*	*Sebastes* sp.
Cabezon	*Scorpaenichthys marmoratus*	Sargo	*Anisotremus davidsonii*
Flatfish*	Species of bothids and pleuronectids	Sculpin	*Scorpaena guttata*
Halfmoon	*Medialuna californiensis*	Seabass, white	*Cynoscion nobilis*
Halibut, California	*Paralichthys californicus*	Sheephead, California	*Pimelometopon pulchrum*
Lingcod	*Ophiodon elongatus*	Swordfish	*Xiphias gladius*
Mackerel, jack	*Trachurus symmetricus*	Wolf-eel	*Anarrhichthys ocellatus*
Mackerel, Pacific	*Scomber japonicus*	Yellowfin croaker	*Umbrina roncador*
Moray, California	*Gymnothorax mordax*	Yellowtail, California	*Seriola dorsalis*
		Mollusks	
Abalone*	*Haliotis* sp.	Scallop, rock	*Hinnites multirugosus*
		Crustaceans	
Spider crab	*Loxorhynchus grandis*	Spiny lobster	*Panulirus interruptus*

* Probably more than one kind.

Calif. Fish and Game, 59(1): 73–88. 1973.

FISHES COLLECTED IN MORRO BAY, CALIFORNIA BETWEEN JANUARY, 1968 AND DECEMBER, 1970[1]

HARRY L. FIERSTINE
Biological Sciences Department
California Polytechnic State University
San Luis Obispo, California 93401

KURT F. KLINE
Department of Genetics
University of California
Davis, California 95616

and

GREGORY R. GARMAN
Department of Zoology
Oregon State University
Corvallis, Oregon 97330

Sixty-six species of fish were collected in Morro Bay between January, 1968 and December, 1970. The bay was divided into five ecological zones. Zone I was characterized by sandy beaches with little algae and contained 10 species. Zone II contained 35 species and was characterized by a sandy-silt bottom with some *Zostera* and kelp beds scattered among commercial piers. Zone III contained 31 species and was characterized by more *Zostera* beds and fewer commercial developments than Zone II. Zone IV contained 30 species and was characterized by large expanses of shallow *Zostera* beds dissected by very narrow channels. Zone V was an estuary with a mud bottom and contained 13 species.

Thirty-seven percent of the catch belonged to the family Embiotocidae of which the black perch and shiner perch contributed 22% of the catch. Twelve species were captured during six or more months of the year and probably are annual residents. Twenty-six species were collected during a single month and probably are seasonal or occasional visitors.

INTRODUCTION

Morro Bay is a shallow, 2,000-acre coastal bay in central San Luis Obispo County, California. Much of its northern and northeastern shorelines contains commercial developments, but the remainder of the shoreline is only partially developed. At times, local governments and citizens have contemplated changes that could alter the existing ecology in both the developed and undeveloped sections.

There exists only a brief report on the fish fauna in Morro Bay (California Department of Fish and Game 1966); however, individual fishes are mentioned in scattered publications (Miller and Gotshall 1965; Smith 1964). The California report states that eel grass beds are utilized for spawning and nursery areas of California halibut, jack smelt, and surfperch. In addition, the report states that the California halibut, starry flounder, sand sole, jack smelt, four species of perch,

[1] Accepted for publication July 1972.

leopard and horn sharks, sting rays and skates are the chief contributors to the sport fishery. Although these observations are valuable, much more specific information is necessary in order to assess the ecological impact of proposed developments. As a first step, the aim of the present study was to identify the fish species that live in Morro Bay and to determine their seasonal and geographical distribution within the bay.

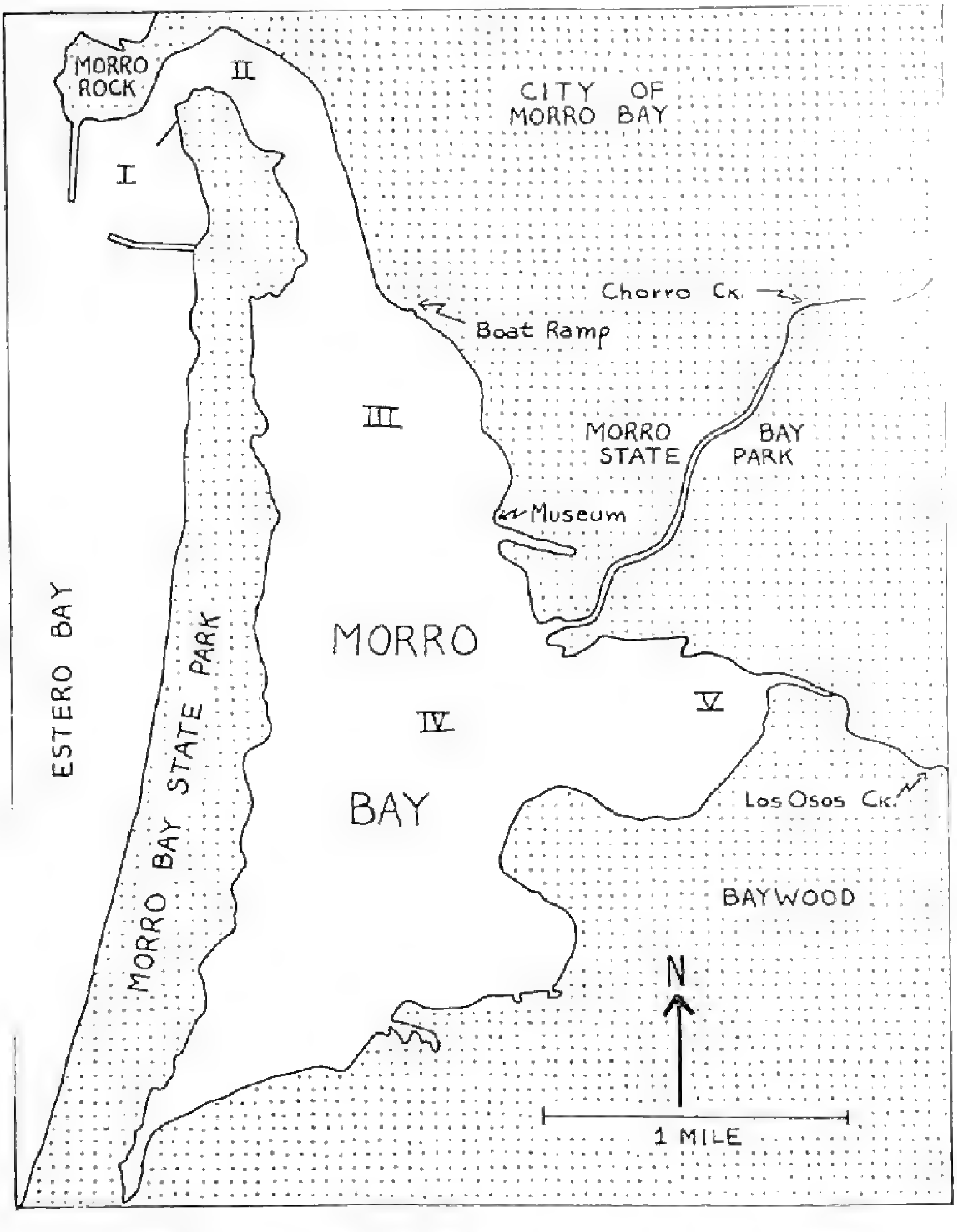


FIGURE 1. Map of Morro Bay with major landmarks and collecting zones.

MATERIALS AND METHODS

Locality Information

Morro Bay (Figure 1) is in San Luis Obispo County, California, approximately 100 miles south of Monterey and 63 miles north of Point Conception. It is formed by the drainage of Chorro and Los Osos creeks and is separated from Estero Bay by a barrier sand bar. Breakwaters surround its entrance to Estero Bay and a narrow dredged channel is present throughout its length. The northern one-third of the bay is within the city limits of Morro Bay and the middle third of the eastern shore and the southern two-thirds of the western shore (sandspit) are within the confines of Morro Bay State Park. The remainder of the southern and eastern shores is bordered by scattered homes and businesses that come under the jurisdiction of San Luis Obispo County.

At mean high tide, about 2,000 acres are covered with water; and at low low tide about 1,400 acres of mudflats are exposed. The currents that flow through the bay during tidal exchange are strong and carry a large silt load which often limits visibility to several inches. The depth ranges at mean lower low tide from 1.5 ft on the mudflats to 22.5 ft in the deepest part of the channel.

Collection Zones Within the Bay

The bay was divided into five collecting zones (Figure 1). Zone I was from the bay mouth north to Morro Rock. This zone has a coarse sand bottom and represents a habitat close to that found in adjacent areas of Estero Bay. Zone II was from Morro Rock, through the commercial area, to the public boat ramp. This zone has a mud-sand bottom and represents an area greatly altered by man. Also, this zone marks the beginning of the *Zostera* beds and contains scattered, small *Macrocystis* beds. Zone III is small and extends from the public boat ramp to the Morro Bay State Park Museum. It represents a transitional area between Zones II and IV and contains a mixture of commercially developed and undeveloped shoreline. Zone IV is the largest and extends from the museum throughout the rest of the bay, except for the estuarine channels of Chorro and Los Osos creeks. This zone contains extensive *Zostera* beds and a silty-mud bottom upon which oysters are commercially grown. Zone V is the estuarine area formed from Chorro and Los Osos creeks. Although this area is hard to define, in actual practice only Los Osos Creek was studied in this report (Chorro Creek estuary lies within Morro Bay State Park, and permission to collect fishes there was not obtained). This zone includes about 1 mile of stream channel from a region of freshwater (salinity = .07‰) at low tide to marine water (salinity = 34‰) at low tide. Most of Zone V collections were taken from stretches of the stream with intermediate salinity.

The zones chosen for sampling on a particular date were not picked randomly, but were biased by the avoidance of bay boating activity, by weather conditions, and by the need to collect a particular species for scientific or educational studies.

Collection Techniques

Most collections were made with an otter trawl operated from an 18-ft boat. The cork-line of the otter trawl was 15 ft long and the cod end contained 1.5 inch stretched mesh. Hook-and-line fishing, scuba and spearfishing, beach and common-sense seines, and dip nets at the night-light station were other techniques employed to collect fish.

Collections were not made on a regular calendar basis and few collections were made between August and October. The otter trawl collected more fish at low tide when the fish were concentrated in the channels. Results were quite poor in the channel at high tide; therefore, most otter trawl collections were made at low low tides.

Names of Fishes and Measurements

Common and scientific names (Tables 1–5) follow American Fisheries Society (1970). All measurements are given in millimeters and total length is used exclusively for the cartilaginous fishes and standard length is used exclusively for the bony fishes.

RESULTS

Approximately 1,600 fish that belong to 66 species were taken in Morro Bay, California between January, 1968 and December, 1970 (Tables 1–5). Thirty-seven percent of the specimens belong to the family Embiotocidae of which the black perch and the shiner perch contributed to 22% of the catch. Twelve species were captured during 6 months or more of the year and probably are annual residents, whereas 26 species were collected only during a single month and probably are seasonal or occasional visitors of Morro Bay.

Ten species were captured in Zone I, and Zones II-IV contained approximately the same number of species: 35, 31, and 30, respectively. Zone V contained 13 species. Zone I had only one species restricted to it, whereas 16 species were collected only in Zone II. Zones III, IV, and V respectively had 6, 7, and 8 restricted species. Sharks and rays were more or less limited to Zones III and IV.

Reproductive activity was often obvious. Empty egg cases of horn sharks were floating in the bay during January. Shiner perch and sharpnose seaperch gave birth when captured during May and June and the female northern midshipmen were distended with eggs during July. At other times, only postlarval or juvenile stages were found. For example, primarily the larval stages of the northern anchovy and juveniles of the lingcod were attracted to the night light. In the case of the northern anchovy, the average size became progressively larger from March through July. Juvenile English sole and speckled sanddabs were the only ages collected and visual observations made while skindiving indicate that they were abundant on the open-sand bottom during the early summer.

TABLE 1. Names, Number of Individuals, Length and Month of Occurrence of Fishes Collected in Zone I of Morro Bay, California Between January, 1968 and December, 1970 [a]

Common and scientific names	Months of capture											
	Jan	Feb.	Mar.	April	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.
Big skate *Raja binoculata*	--	--	--	--	--	--	1 (195)	--	--	--	--	--
Striped seaperch *Embiotoca lateralis*	--	--	--	--	--	--	1 (105)	--	--	--	--	--
Walleye surfperch *Hyperprosopon argenteum*	--	--	--	4 (125-193)	--	--	--	--	--	--	--	--
Rubberlip seaperch *Rhacochilus toxotes*	--	--	--	--	--	--	1 (110)	--	--	--	--	--
Lingcod *Ophiodon elongatus*	--	--	--	--	--	--	1 (124)	--	--	--	--	--
Speckled sanddab *Citharichthys stigmaeus*	--	--	--	--	--	--	2 (80-85)	--	--	--	--	--
California halibut *Paralichthys californicus*	--	--	1 (NR)	--	--	--	1 (355)	--	--	--	--	--
Diamond turbot *Hypopsetta guttulata*	--	--	4 (185-200)	--	--	--	4 (209-256)	--	--	--	--	--
Starry flounder *Platichthys stellatus*	--	--	--	--	--	--	1 (260)	--	--	--	--	--
Sand sole *Psettichthys melanostictus*	--	--	--	--	--	--	5 (185 207)	--	--	--	--	--

[a] Numbers outside parentheses refer to the number of specimens collected and numbers within parentheses refer to size range (mm, standard length). NR signifies that size was not recorded.

TABLE 2. **Names, Number of Individuals, Length and Month of Occurrence of Fishes Collected in Zone II of Morro Bay, California Between January, 1968 and December, 1970 ***

Common and scientific names	Months of capture											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gray smoothhound *Mustelus californicus*	--	--	--	1 (750)	--	--	--	--	--	--	--	--
Pacific herring *Clupea harengus pallasi*	--	--	--	--	--	1 (48)	--	--	--	--	--	--
Pacific sardine *Sardinops sagax*	--	--	--	--	2 (273-290)	--	--	--	--	--	--	--
Northern anchovy *Engraulis mordax*	--	--	23 (22-51)	30 (28-57)	160 (22-70)	120 (26-96)	12 (22-80)	--	--	--	--	--
Kelp pipefish *Syngnathus californiensis*	--	--	--	--	1 (225)	2 (205-215)	--	--	--	--	--	--
Bay pipefish *Syngnathus griseolineatus*	--	--	--	1 (87)	--	--	--	--	--	--	--	--
Jack mackerel *Trachurus symmetricus*	--	--	--	--	--	3 (181-203)	--	--	--	--	--	--
Black perch *Embiotoca jacksoni*	1 (204)	--	7 (NR)	22 (NR)	1 (360)	--	--	--	--	15 (NR)	2 (150-250)	--
Striped seaperch *Embiotoca lateralis*	--	--	--	5 (NR)	--	--	--	--	--	--	--	--
Walleye surfperch *Hyperprosopon argenteum*	--	--	--	--	1 (196)	--	--	--	--	--	--	--
Shiner perch *Cymatogaster aggregata*	--	--	1 (NR)	--	--	--	--	--	--	--	--	--
Rainbow seaperch *Hypsurus caryi*	--	--	--	--	1 (170)	--	--	--	--	--	--	--
Sharpnose seaperch *Phanerodon atripes*	--	--	--	2 (200-211)	8 (175-238)	11 (188-221)	--	--	--	--	--	--
White seaperch *Phanerodon furcatus*	--	--	5 (200-205)	7 (169-186)	--	--	--	--	--	--	--	--
Pile perch *Rhacochilus vacca*	--	--	8 (NR)	--	--	--	--	--	--	--	--	--
Calico rockfish *Sebastes dalli*	--	--	--	--	--	--	3 ([illegible]-115)	--	--	--	--	--

Blue rockfish *Sebastes mystinus*	--	--	--	--	--	--	1 ([illegible])		--	--	--	-
Bocaccio *Sebastes paucispinis*	--	--	--	-	--	8 (42-81)	8 (62-[illegible])			4 (109-126)	--	--
Grass rockfish *Sebastes rastrelliger*	--	--	--	--	--	1 ([illegible])			--	--	--	--
Olive rockfish *Sebastes serranoides*	--	--	--	--	--		1 (150-210)		--	--	-	--
Lingcod *Ophiodon elongatus*	--	--	5 (75-320)	3 (75-79)	2 (69-70)	20 (18-80)	8 (140-280)		--	--	--	--
Painted greenling *Oxylebius pictus*	--	--	--	1 (119)	-	--	1 (130)	-	1 (NR)	--	--	--
Pacific staghorn sculpin *Leptocottus armatus*	--	--	--	--	--	--	1 (86)	3 (72-140)	--		--	--
Cabezon *Scorpaenichthys marmoratus*	--	--	--	-	-	--	3 (53-245)	--	-	--	--	--
Penpoint gunnel *Apodichthys flavidus*	--	--	2 (108-125)	--	--	--	--	-	-	-	--	--
Rockweed gunnel *Xererpes fucorum*	--	--	1 (25)	-	--	--	--	--	--	--	--	--
Pacific pompano *Peprilus simillimus*	--	--	--	--	5 (120-147)	--	-	--	--	--	--	--
Topsmelt *Atherinops affinis*	--	--	--	4 (93-110)	9 (101-185)	5 (51-60)	8 (59-195)	--	--	--	--	--
Jacksmelt *Atherinopsis californiensis*	--	--	--	--	2 (91-123)	2 (47-72)	--	--	--	--	--	
California halibut *Paralichthys californicus*	--	--	5 (240-390)	1 (150)	--	--	-	--	-	--	--	--
Diamond turbot *Hypopsetta guttulata*	--	--	3 (190-196)	2 (NR)	--	--	1 (226)	--	-	--	--	--
Starry flounder *Platichthys stellatus*	--	--	--	1 (500)	--	--	--	--	--	--	--	--
C-O sole *Pleuronichthys coenosus*	--	--	--	1 (180)	--	--	--	--	--	--	--	--
Spotted turbot *Pleuronichthys ritteri*	--	--	1 (200)	--	--	--	--	--	--	--	--	--
Plainfin midshipman *Porichthys notatus*	--	--	--	--	1 (160)	--	1 (185)	--	--	-	--	--

* Numbers outside parentheses refer to the number of specimens collected and numbers within parentheses refer to size range (mm. standard length). NR signifies that size was not recorded.

TABLE 3. **Names, Number of Individuals, Length and Monthof Occurrence of Fishes Collected in Zone III of Morro Bay, California Between January, 1968 and December, 1970 ***

Common and scientific names	Months of capture											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.
Leopard shark *Triakis semifasciata*	--	--	--	--	--	2 (220–240)	--	--	--	--	--	--
Pacific angel shark *Squatina californica*	1 (1070)	--	--	--	--	--	--	--	--	--	--	--
Round stingray *Urolophus halleri*	--	--	--	2 (315–325)	--	--	--	--	--	--	--	1 (NR)
Bat ray *Myliobatis californica*	--	--	--	1 (570)	--	--	1 (1310)	--	--	--	--	--
Jack mackerel *Trachurus symmetricus*	--	--	--	--	14 (133–160)	--	--	-	--	--	--	--
Black perch *Embiotoca jacksoni*	--	--	--	5 (233–250)	10 (42–125)	1 (NR)	--	--	1 (155)	--	27 (88–112)	1 (165)
Striped seaperch *Embiotoca lateralis*	--	--	--	--	2 (135–175)	--	--	--	--	--	--	--
Walleye surfperch *Hyperprosopon argenteum*	--	--	--	--	--	10 (NR)	--	--	--	--	2 (110–120)	--
Shiner perch *Cymatogaster aggregata*	2 (70)	--	--	--	35 (NR)	100 (NR)	10 (42–108)	7 (30–90)	--	--	--	--
White seaperch *Phanerodon furcatus*	--	--	1 (NR)	7 (NR)	--	1 (165)	--	--	--	--	--	--
Rubberlip seaperch *Rhacochilus yoxotes*	--	--	--	--	--	1 (285)	--	--	--	--	--	--
Pile perch *Rhacochilus vacca*	--	--	--	--	--	1 (240)	--	--	--	--	--	1 (240)
Arrow goby *Clevelandia ios*	--	--	2 (29–32)	--	3 (10–15)	--	-	-	-	-	--	--
Brown rockfish *Sebastes auriculatus*	--	--	--	--	--	--	[illegible] 150)	--	--	--	--	--

Bocaccio *Sebastes paucispinis*	--	--	--	--	1 (42)	--	--	--	--	--	--	--
Grass rockfish *Sebastis rastrelliger*	--	--	--		2 (72-110)	--	-	--	--	--	--	--
Lingcod *Ophiodon elongatus*	--	--	--	--	--	--	2 (75-[illegible])	--	--	--	--	--
Smoothhead sculpin *Arteduis lateralis*	--	--	--	--	--		--	--	--	--	1 (55)	--
Pacific staghorn sculpin *Leptocottus armatus*	12 (35-136)	--	--	--	1 (145)	--	--	1 (70)	--	--	1 (137)	--
Giant kelpfish *Heterostichus rostratus*	--	--	--	--	1 (120)	--	-	--	--	--	--	--
Monkeyface prickleback *Cebidichthys violaceus*	--	--	--	--	--	--	--	--	--	--	1 (250)	--
Topsmelt *Atherinops affinis*	33 (45-184)	--	--	--	--	--	--	--	--	--	--	--
Jacksmelt *Atherinopsis californiensis*	--	--	--	--	10 (120-235)	--	-	--	--	--	--	--
Speckled sanddab *Citharichthys stimageus*	4 (41-82)	--	--	--	--	--	2 (74-82)	--	--	--	--	--
California halibut *Paralichthys californicus*	--	--	--	5 (500-580)	--	4 (NR)	--	--	--	--	--	1 (325)
Diamond turbot *Hypopsetta guttulata*	--	--	10 (185-260)	--	--	--	2 (221-230)	--	--	--	--	1 (215)
English sole *Parophrys vetulis*	--	--	--	--	9 (29-54)	2 (70-80)	22 (53-95)	--	--	--	2 (100-105)	--
Starry flounder *Platichthys stellatus*	-- 1 (102)	--	--	3 (210-460)	--	8 (170-235)	--	--	--	--	--	3 (280-325)
Sand sole *Psettichthys melanostictus*	--	--	--	--	--	--	--	--	--	--	--	1 (225)
California tonguefish *Symphurus atricauda*	--	--	--	--	--	--	--	1 (40)	--	--	--	--
Kelp clingfish *Rimicola muscarum*	1 (33)	--	--	--	--	--	--	--	--	--	--	--

* Numbers outside parentheses refer to the number of specimens collected and numbers within parentheses refer to size range (mm, standard length). NR signifies that size was not recorded

TABLE 4. **Names, Number of Individuals, Length and Month of Occurrence of Fishes Collected in Zone IV of Morro Bay, California Between January, 1968 and December, 1970 ***

Common and scientific names	Months of capture											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Horn shark *Heterodontus francisci*	4 (800-1000)	--	--	--	2 (620-830)	--	--	--	--	--	--	--
Gray smoothhound *Mustelus californicus*	--	--	1 (320)	--	1 (780)	--	--	--	--	--	--	--
Leopard shark *Triakis semifasciata*	--	--	--	--	--	1 (495)	1 (212)	--	--	--	--	--
Thornback *Platyrhinoidis triseriata*	--	--	--	--	--	2 (470-500)	--	--	--	--	--	--
Shovelnose guitarfish *Rhinobatos productus*	--	1 (1150)	1 (1000)	--	--	--	--	--	--	--	--	--
Round stingray *Urolophus halleri*	--	1 (480)	4 (NR)	--	--	1 (NR)	2 (NR)	--	--	--	--	--
Bat ray *Myliobatis californica*	--	--	4 (360-510)	2 (NR)	2 (NR)	--	--	--	--	--	1 (511)	2 (405-470)
California killifish *Fundulus parvipinnis*	--	6 (46-60)	--	--	--	--	--	--	--	--	--	--
Black perch *Embiotoca jacksoni*	--	11 (45-175)	31 (85-195)	--	22 (NR)	7 (140-190)	--	--	--	--	2 (170-188)	--
Walleye surfperch *Hyperprosopon argenteum*	--	5 (120-175)	9 (140-170)	--	--	2 (155)	--	--	--	--	--	--
Shiner perch *Cymatogaster aggregata*	--	--	--	--	30 (NR)	100 (95-115)	--	--	--	--	--	--
Dwarf perch *Micrometrus minimus*	--	1 (80)	--	--	--	--	--	--	--	--	2 (88-103)	--
White seaperch *Phanerodon furcatus*	--	--	11 (150-200)	--	--	--	--	--	--	--	--	9 (155-190)

Rubberlip seaperch *Rhacochilus toxotes*	--	--	1 (265)	--	--	--	--	--	--	--	3 (95-105)	--
Pile perch *Rhacochilus vacca*	--	8 (170-220)	7 (101-270)	--	--	--		--	--	--	11 (96-211)	--
Arrow goby *Clevelandia ios*	1 (37)	--	--	--	--	--	--	--	--	--	--	--
Bay goby *Lepidogobius lepidus*	1 (75)	--	--	--	--	--	--	--	--	--	--	--
Lingcod *Ophiodon elongatus*	--	1 (216)	--	--	--	--	--	--	--	--	--	--
Pacific staghorn sculpin *Leptocottus armatus*	--	1 (156)	--	--	--	--	--	--	--	--	--	--
Crevice kelpfish *Gibbonsia montereyensis*	--	--	1 (87)	--	--	--	--	--	--	--	--	--
Rockweed gunnel *Xererpes fucorum*	1 (109)	--	--	--	--	--	--	--	--	--	--	--
Topsmelt *Atherinops affinis*	--	8 (13-60)	--	--	--	--	--	--	--	--	--	--
Jacksmelt *Atherinopsis californiensis*	--	2 (290-320)	--	--	--	--	--	--	--	--	--	--
Speckled sanddab *Citharichthys stigmaeus*	--	--	2 (98-100)	--	--	4 (71-88)	36 (65-115)	--	--	--	15 (75-107)	--
California halibut *Paralichthys californicus*	--	5 (175-275)	5 (220-453)	--	2 (180-210)	3 (175-315)	--	--	--	--	2 (226-237)	--
Diamond turbot *Hypopsetta guttulata*	--	1 (150)	3 (192-210)	--	--	2 (200-250)	1 (240)	--	--	--	--	--
English sole *Parophrys vetulus*	--	--	2 (81-92)	--	--	2 (70-80)	--	--	--	--	10 (92-121)	--
Starry flounder *Platichthys stellatus*	--	1 (230)	6 (18-450)	--	--	1 (220)	6 (245-365)	--	--	--	1 (118)	--
Sand sole *Psettichthys melanostictus*	--	--	--	--	1 (170)	--	--	--	--	--	--	--
Plainfin midshipman *Porichthys notatus*	--	--	--	--	--	--	2 (149-155)	--	--	--	--	--

* Numbers outside parentheses refer to the number of specimens collected and numbers within parentheses refer to size range (mm, standard length). NR signifies that size was not recorded.

TABLE 5. Names, Number of Individuals, Length and Month of Occurrence of Fishes Collected in Zone V of Morro Bay, California Between January, 1968 and December, 1970 *

Common and scientific names	Months of capture											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Steelhead rainbow trout *Salmo gairdneri gairdneri*	--	--	--	1 (94)	--	--	--	--	--	--	--	--
California killifish *Fundulus parvipinnis*	--	15 (40-80)	--	5 (72-86)	--	--	--	--	--	--	--	--
Mosquito fish *Gambusia affinis*	--	6 (22-31)	--	--	--	--	--	--	--	--	--	--
Threespine stickleback *Gasterosteus aculeatus*	1 (35)	17 (25-48)	--	--	3 (19-31)	--	--	--	--	--	--	--
Green sunfish *Lepomis cyanellus*	--	5 (43-123)	--	1 (40)	--	--	--	--	--	--	--	--
Shiner perch *Cymatogaster aggregata*	--	--	--	--	11 (36-113)	--	--	--	--	--	--	--
Tidewater goby *Eucyclogobius newberryi*	22 (14-36)	35 (19-37)	--	--	1 (31)	--	--	--	--	--	--	--
Longjaw mudsucker *Gillichthys mirabilis*	--	3 (58-120)	--	--	--	--	--	--	--	--	--	--
Prickly sculpin *Cottus asper*	--	--	--	--	3 (19-31)	--	--	--	--	--	--	--
Riffle sculpin *Cottus gulosus*	--	2 (130-137)	--	--	--	--	--	--	--	--	--	--
Pacific staghorn sculpin *Leptocottus armatus*	57 (18-47)	36 (24-113)	--	1 (121)	6 (32-73)	--	--	--	--	--	--	--
Topsmelt *Atherinops affinis*	1 (82)	--	--	--	5 (76-86)	--	--	--	--	--	--	--
Starry flounder *Platichthys stellatus*	--	1 (80)	--	--	2 (30-45)	--	--	--	--	--	--	--

* Numbers outside parentheses refer to the number of specimens collected and numbers within parentheses refer to size range (mm standard length). NR signifies that size was not recorded.

DISCUSSION

Limitations of Study

The number of inherent biases in this study leads us to avoid precise conclusions on abundance. For example, during May and June shiner perch were so abundant at times that the otter trawl was emptied without counting or measuring specimens in order to return the animals alive to the bay. The northern anchovy was only taken in a night-light station with dip nets and specimens were young of the year which were so abundant at times that only a representative sample was taken. Thus, the estimates of numbers caught in Morro Bay for these two species (and others) are minimal figures.

Various collecting techniques were not employed which would have probably increased the total number of species collected. For example, an ichthyocide would have allowed us to capture the cottids and eel-blennies that we are sure inhabit the crevices in breakwaters and jetties. Boating activity in the narrow channel did not permit us to set gill nets. This technique might have resulted in the capture of more sharks and other active swimming fishes. Visibility in the bay is usually very poor, particularly during the rainy season and, therefore, spearfishing and visual observations were of limited value. A midwater (or surface) trawl would have helped capture the more pelagic fishes.

Certain species of fish, which were not captured, are probably occasional or seasonal visitors to Morro Bay. For example, the Pacific lamprey (*Entosphenus tridentatus*) enters San Luis Obispo Creek (15 miles south of Morro Bay) to spawn during the late winter and spring (Fierstine, unpublished data). This species probably travels through Morro Bay to enter Chorro and Los Osos creeks. Similarly, small steelhead trout are known to inhabit most of the coastal freshwater streams in San Luis Obispo County. Efforts to capture these migratory species in Morro Bay have failed.

Comparison with Northern California Studies

Herald and Simpson (1955) reported 61 species of fish collected from a trash screen at a steam generating plant in south San Francisco Bay. Thirty-one species (51%) are common to those found in Morro Bay. The differences in species composition between these two localities are primarily due to the absence of smelts (Osmeridae), snail fish (Liparidae), different rockfishes (Scorpaenidae), and different cartilaginous fishes from Morro Bay. Herald and Simpson noted a lower abundance of fishes in the summer than in the winter (e.g. 481 specimens were collected on August 13, 1951, compared to 2,352 specimens on February 19, 1951). The most abundant fish was the shiner perch, and its numbers coincided with the winter abundance and the summer decrease. In Morro Bay, the shiner perch was most abundant during the late spring and early summer when the females were distended with live young.

From the Sacramento-San Joaquin estuary, Ganssle (1966) compiled a list of the fishes of San Pablo and Suisun bays, and Messersmith (1966) studied the fishes of Carquinez Strait, an intermediate area joining San Pablo and Suisun bays. Ganssle collected 60 species and Messersmith listed 48 species. The salinity of San Pablo Bay, the

most downstream locality, varied in salinity from 7.9‰ to 16‰ and the salinity of Suisun Bay, the most upstream locality, varied in salinity from 0‰ to 3.3‰. Only 28 species were common between Morro Bay and the San Pablo and Suisun bays. The main reason for the lack of similarity between the two faunas is that the more northern fauna contained five species of smelt, eight anadromous, and 13 freshwater forms.

Herald, et al. (1960) listed seven elasmobranchs and seven teleosts that were caught during 17 shark derbies in Elkhorn Slough, Monterey County, California. Six of the cartilaginous fish and four of the bony fish are common to Morro Bay. One of the bony fish, the striped bass, is caught on hook-and-line inside Morro Bay (Miller and Gotshall, 1965), but it was not taken during our study.

Miller and Gotshall (1965) in a sportfishing survey from Oregon to Point Arguello, California state that the starry flounder, jacksmelt, and California halibut made up 41.3, 19.9, and 17.2%, respectively, of the sportfish (skiff) catch in Morro Bay. Our data supports the fact that the starry flounder and California halibut are among the most abundant of the large sportfish present in the bay.

Comparison with Southern California Studies

Chapman (1963) lists 78 species of fish from Mission Bay, San Diego County, California of which 33 species are common to Morro Bay. A sportfishery survey taken during 1961 showed that four species contributed 57% of the total catch (spotfin croaker, 29%; spotted sandbass, 13%; California halibut, 8.1%; opaleye, 7.0%). Various surfperches contributed 8% of the total catch. Croakers (Sciaenidae), basses (*Paralabrax*) and opaleye are notably absent from Morro Bay. California halibut contributed about 2% of the fish collected in Morro Bay, and it probably contributes much more to the skiff fishery. An account of the sportfishing survey taken from a Morro Bay pier during the late spring of 1969 (McLeod, unpublished data) indicated that the shiner perch (53%), black perch (23%), and jacksmelt (10%) contributed to 86% of the fish caught.

Pinkas, et al. (1968) in a sportfishing survey from Point Conception to the Mexican border lists the species composition of the 1965–66 catch within inland bays. Their definition of an inland bay is any protected water within a jetty that is not considered open or deep-sea; therefore, their survey included many species caught in places other than natural bays with estuaries. They list the white croaker and queenfish as contributing respectively to 35.1 and 17.8% of the total catch. These fishes are frequently caught in the open ocean near Morro Bay (Miller and Gotshall, 1965), but neither was present in our Morro Bay survey.

Two accounts from southern California give just a list of species present. Bane (1968) lists 52 species of fish from upper Newport Bay, Orange County, California. Twenty-six of the species are common to Morro Bay, whereas 44 species are common to Mission Bay. Reish (1968) lists 24 species from Alamitos Bay, Los Angeles County, California. Nineteen species are common to upper Newport Bay and 15 species are common to Morro Bay. Notably absent from both of these southern California studies are the various rockfishes (Scorpaenidae),

whereas, as mentioned above, the croakers (Sciaenidae) and basses (*Paralabrax*) are absent from Morro Bay.

Zonation of Fishes

The restriction of nearly all sharks and rays to Zones III and IV is probably due to the large expanses of tidelands which seem to be rich in invertebrates and serve as feeding grounds. The absence of most embiotocids from Zone I may be due to the absence of *Zostera* and the restricted occurrence of kelp beds. An account of the stomach contents of some Morro Bay fishes (Baldwin, unpublished data) lists gammarid amphipods, which inhabit *Zostera* and kelp, as a major food source for black perch, walleye surfperch, and white seaperch.

Most of the 12 species found in Zone V are euryhaline. The green sunfish and mosquitofish were found at three stations along the stream which varied in salinity at low tide from .13‰ to .21‰. This zone was collected primarily during the rainy season and these fish could have washed further downstream than they preferred.

Unusual Occurrences

Only one species seems important to single out as unusual, since it is more common than normally thought. Smith (1964), in a redescription and reanalysis of the life history of the sharpnose seaperch, described a single female specimen caught by hook-and-line from a pier in Morro Bay on July 11, 1963. This fish measured 181 mm SL and contained ten embryos. The 21 specimens collected in our survey agree with the reproductive activity and occurrence reported by Smith, however, our specimens were all caught on whole, live anchovies at a night-light station (Tremper, unpublished data) and might indicate nocturnal habits for this species. All 21 specimens were females and attempts to collect this species during the winter failed.

ACKNOWLEDGMENTS

This study could not have been completed without the aid of numerous students, faculty, and friends who assisted with the collections. Particular mention should go to Joni Valladao, Don Baldwin, Barry McLeod, and Gary Tremper who contributed valuable data as well as manual labor. Professors Fred Clogston, Richard Krejsa, and Dave Montgomery offered specimens to us from their class field trips. The otter trawl and other pieces of equipment were purchased by a generous grant-in-aid of research from the Society of Sigma Xi. Darlene Miller and Patricia Knapp typed the various drafts of the manuscript and Drs. Lo Chai Chen, Austin Pritchard, and Thomas Richards have read the manuscript and have offered editorial assistance.

REFERENCES

American Fisheries Society. 1970. A list of common and scientific names of fishes from the United States and Canada. 3rd ed., Amer. Fish Soc. Spec. Publ. 6, 150 p.

Bane, Gilbert W. 1968. Fishes of the upper Newport Bay. Mus. of Systematic Biol., Univ. Calif. Irvine, Research Series (3): 1–114.

Barrett, Elinore M. 1963. The California oyster industry. Calif. Dep. Fish and Game, Fish Bull. (123): 1–103.

California Department of Fish and Game. 1966. Report on the natural resources of Morro Bay and proposal for comprehensive area plan. Sacramento. 37 p. mimeo.

Chapman, Gordon A. 1963. Mission Bay, a review of previous studies and the status of the sportfishery. Calif. Fish Game 49(1): 30–43.

Ganssle, David. 1966. Fishes and decapods of San Pablo and Suisun Bays, p. 64–94. *In* D. W. Kelley (ed.). Ecological studies of the Sacramento-San Joaquin estuary, Part I, Calif. Dep. Fish and Game, Fish Bull. (133): 1–133.

Herald, Earl S. and Donald A. Simpson. 1955. Fluctuations in abundance of certain fishes in south San Francisco Bay as indicated by sampling at a trash screen. Calif. Fish Game 41(4): 271–278.

Herald, Earl S., Walter Schneebeli, Norval Green and Kenneth Innes. 1960. Catch records for seventeen shark derbies held at Elkhorn Slough, Monterey Bay, California, Calif. Fish Game 46(1): 59–67.

Messersmith, James. 1966. Fishes collected in Carquinez Strait in 1961–1962, p. 57–63. *In* D. W. Kelley ed. Ecological studies of the Sacramento-San Joaquin estuary, Part I. Calif. Dep. Fish and Game, Fish Bull. (133): 1–133.

Miller, Daniel J. and Daniel Gotshall. 1965. Ocean sportfish catch and effort from Oregon to Point Arguello, California. Calif. Dep. Fish and Game, Fish Bull. (130): 1–130.

Pinkas, Leo, Malcolm S. Oliphant, and Charles W. Haugen. 1968. Southern California marine sportfishing survey: private boats, 1964; shoreline, 1965-66. Calif. Dep. Fish and Game, Fish Bull. (143): 1–42.

Reish, Donald J. 1968. Marine life of Alamitos Bay. Seaside Printing Co., Long Beach, Calif. 92 p.

Smith, J. Gary. 1964. Notes on the life history and a description of the sharpnose seaperch, *Phanerodon atripes* (Jordan and Gilbert) Calif. Fish Game 50(1): 42–47.

NOTES

ALBINISM IN THREE SPECIES OF MARINE INVERTEBRATES FROM SOUTHERN CALIFORNIA

Although albinism in marine invertebrates is by no means a common phenomenon, it is not so rare as the paucity of published reports would seem to indicate. The occasional visitor to the shore probably will never see a single example of it. But collectors, researchers, divers, and commercial fishermen surely must find a number of specimens which remain unreported. This brief paper is offered in the hope that it will stimulate documentation of future discoveries of invertebrate albinism.

The species under consideration, *Patiria miniata*, *Renilla köllikeri*, and *Ophioderma panamense*, were collected during the years 1970–1971. All three are common in southern California, a situation which naturally increases the probability of occasional albinism.

Appreciation and thanks are due to Mr. David Theis, who has always been an eager colleague on early morning low-tide expeditions, despite having to go to work a few hours later. The author is equally indebted to Mr. Donald Theis for the excellent photographs which accompany this report. Both reside in Redondo Beach, California.

Renilla köllikeri Pfeffer, 1886

An albino specimen of this coelenterate was taken intertidally at Newport Bay on June 20, 1970, on a —1.6 tide at 5:06 AM. Although *Renilla* once occurred in Newport Bay "by the hundred" (Ricketts and Calvin, 1964), specimens are at present quite uncommon. It is therefore remarkable that an albino should be taken. The specimen was preserved, unrelaxed, in 10% formalin solution, a step necessitated by the rapidly declining state of its health. The preservative did not alter the animal's original color, Figure 1.

Patiria miniata (Brandt, 1835)

An albino specimen was taken intertidally at Lunada Bay, Palos Verdes peninsula, on May 23, 1971, Figure 2. Maximum low tide level was —1.4 at 3:18 AM. Representatives of the species are not uncommon at this location. *Patiria* occurs in a number of "normal" color forms from pale gray-tan through yellow, orange, red, and purple, and including a wide variety of mottled combinations of these colors. The albino form is quite distinct from even the most pale of these color varieties.

Ophioderma panamense Lütken, 1872

An albino specimen of this ophiuroid was collected on February 11, 1970, off Flat Rock, Palos Verdes peninsula, by a SCUBA diver, Figure 3. Depth of occurence was approximately 25 ft. Specimens occur commonly at this location. The specimen was preserved in 70% isopropyl alcohol, which did not alter the animal's original color.

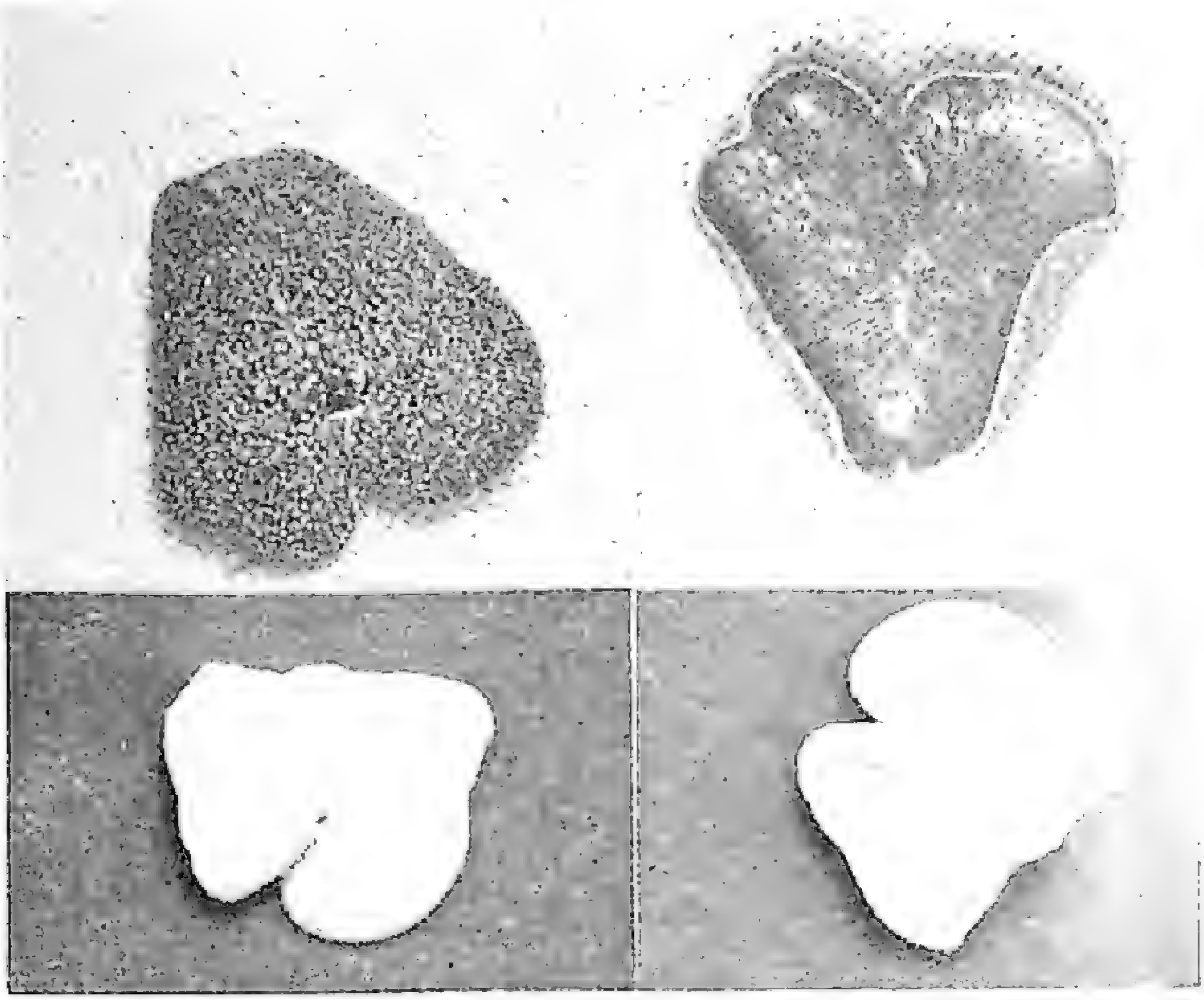


FIGURE 1. *Renilla köllikeri.* (a) Dorsum, typical rich blue coloration. (b) Ventrum, typical red to violet. Photographed from life. (c) Dorsum, albino. (d) Ventrum, albino. Photographs of a preserved specimen.

FIGURE 2. *Patiria miniata.* (a) Aboral surface, deep red coloration. (b) Oral surface, typical pale yellow-white. Photographed from life. (c) Aboral surface, albino. (d) Oral surface, albino. Photographed from life.

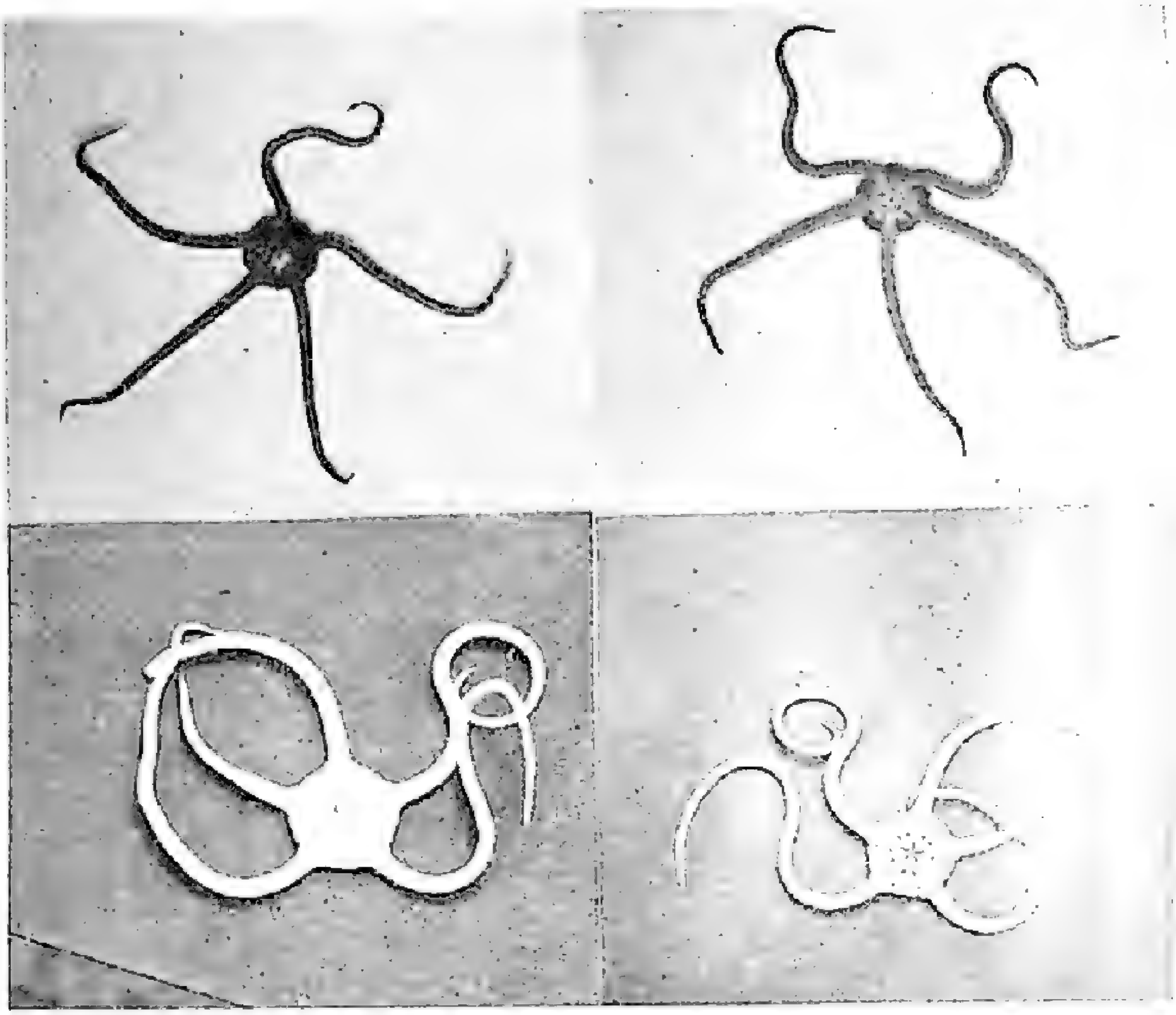


FIGURE 3. *Ophioderma panamense.* (a) Aboral surface, typical chocolate coloration. (b) Oral surface, typical pale brown. Photographed from life. (c) Aboral surface, albino. (d) Oral surface, albino. Photographs of a preserved specimen.

REFERENCES

Ricketts, Edward F., and Jack Calvin. 1964. Between Pacific tides. Stanford Univ. Press, Stanford, Calif. 516 p.

—*Vernon L. Human, 2510 Whitney Avenue, Summerland, California 93067.* *Accepted August 1972.*

OCCURRENCE OF THE RETICULATE SCULPIN, *COTTUS PERPLEXUS,* IN CALIFORNIA, WITH DISTRIBUTIONAL NOTES ON *COTTUS GULOSUS* IN OREGON AND WASHINGTON

In discussing the relationships of *Cottus perplexus* Gilbert and Evermann and *C. gulosus* (Girard), Robins and Miller (1957) did not cover the identity of the *Cottus* species inhabiting the Rogue River drainage and adjacent coastal streams in Oregon. The most abundant representative of the genus in the Rogue is *C. perplexus*, which has often been collected from the Illinois and Applegate river systems close to the California-Oregon border. *Cottus perplexus* was originally described and figured by Gilbert and Evermann (1894), on the basis of material collected in the Skookumchuck River near Chehalis, Washington.

One collection, catalogued at Oregon State University, Department of Fisheries and Wildlife as No. 3524, was taken from the Middle Fork of the Applegate River on the California side of the border on March 2, 1971, by Dr. F. H. Everest. So the species is part of the California fauna in the Rogue drainage, even though it is not known from coastal streams south of the Rogue. *C. perplexus* differs from *C. gulosus* in the characters compared in Table 1, adapted from Bailey and Bond, 1963. Specimens from the Applegate River lack palatine teeth, have the characteristic short head and robust body of coastal *perplexus*, and have the usual coloration and ray counts. The mouth is short but wide, equaling the body width behind the pectorals in males.

TABLE 1. Comparison of *Cottus gulosus* and *C. perplexus*

Character	*gulosus*	*perplexus*
Palatine teeth	Present	Absent
Preopercular spines	(2+) 3 or 3+ (1); usually 3	(1) 2 to 3 (4); usually 2 or 2+
Lateral line (specimens over 50 mm):		
Percentage in which complete	23	36
Pores	(21) 22–36 (38)	(15) 22–32 (33)
Pectoral rays	(14) 15 or 16 (17)	(13) 14 or 15 (16)
Head length (percent of standard length)	(30) 31–36 (39)	(23) 28–33 (38)
Mouth size:		
Maxilla extends to below	Posterior part of eye	Anterior part of eye
Overall width	Equals or exceeds body width behind pectorals	Less than body width behind pectorals
Dorsal fins	Conjoined or separate	Usually conjoined, most often broadly so
Pigmentation	Usually with large irregular dark blotches on a lighter background	Variable, usually of vermiculations and small blotches that do not have high contrast with background

Other *Cottus* species known from the Rogue River drainage are *C. aleuticus* Gilbert and *C. asper* Richardson, both of which occur in most coastal streams in northern California and Oregon.

Although Robins and Miller (1957) were correct in the statement that most of the *C. gulosus* records from Washington and northern Oregon are based on *perplexus*, *gulosus* does range as far north as the Bogachiel River at La Push, Washington, but its distribution on the Washington coast is discontinuous. It does not seem to occur upstream from the Kalama River in the Columbia drainage (Reimers and Bond, 1967) and appears to have a spotty distribution on the Oregon coast, where it is known from the following drainages: Necanicum River, Elk Creek (Clatsop County), Fogarty Creek, N. Fk. Alsea River, Yachats River, Cummins Creek, Tenmile Creek (Lane County), Siuslaw River, Maple Creek, Umpqua River, and Coquille River.

Cottus gulosus is not known to occur between the Coquille River and the California border.

REFERENCES

Bailey, R. M., and C. E. Bond. 1963. Four new species of freshwater sculpins, genus *Cottus*, from western North America. Occasional papers of the Museum of Zoology. Univ. of Michigan. No. 634. 27 p.

Gilbert, Charles, and Barton W. Evermann. 1894. A report upon investigations in the Columbia River basin, with descriptions of four new species of fishes. *In* Report of the Commissioner of Fish and Fisheries on investigations in the Columbia River basin in regard to the salmon fisheries. U.S. Senate Misc. Doc. 200, Fifty-third Congress, second session, p. 19–54. pls. 4–13. (Reprinted in Bull. U.S. Fish Comm. 14: 169–204, pls. 16–25.)

Reimers, P. E., and C. E. Bond. 1967. Distribution of fishes in tributaries of the lower Columbia River. Copeia 1967 (3) : 541–550.

Robins, C. Richard, and Robert Rush Miller. 1957. Classification, variation, and distribution of the sculpins, genus *Cottus*, inhabiting Pacific slope waters in California and southern Oregon, with a key to the species. Calif. Fish Game 43(3) : 213–233.

—Carl E. Bond, Department of Fisheries and Wildlife, Oregon State University. *Accepted September, 1971.*

BOOK REVIEWS

Modern Fresh and Salt Water Fly Fishing

By Charles F. Waterman; Winchester Press, N.Y., 1972; XIV + 368 p. Illustrated. $8.95.

Most of the information in this book can be found in numerous other books on fly fishing. Mr. Waterman has drawn it all together in one spot. There are the usual chapters on equipment and casting techniques, followed by information on black bass, trout and salmon and how to fish for them. The chapters on salt water species and techniques are probably the most important parts of the book. Little has been written on this relatively new branch of fly fishing aside from magazine articles and the author has done a good job of describing the various species available to the fly rodder, how to locate them, and what to use. The book is well illustrated and will be of value to fly fishermen who want to fish for something other than trout.—*K. A. Hashagen, Jr.*

California Water: A Study in Resource Management

By David Seckler, Editor: Univ. of California Press, Berkeley, Calif. 1971; 361 p. $15.00.

This book is a collection of more or less independent chapters written by a variety of contributors. It covers the topic of water and its use in California very broadly The book first reviews the California Water Plan and its implementation rathe briefly. It then presents a series of chapters on each of three topics: the variou types of water use, the technology of water supply sources which are primaril alternatives to storing and transporting surface runoff, and the politics and economic of water resource development.

Two chapters in the water use section deal with fishery resources directly. One is a discussion of the value of free flowing streams by Frank H. Bollman. Bollman presents a good discussion of the value of flowing water and the need for defining the economic value quantitatively. Unfortunately he does not offer an approach to defining such values.

The second fishery related chapter is a discussion of the biological implications of reducing freshwater flows into San Francisco Bay by Charles R. Goldman. This chapter presents some aspects of the problem well, but it is not a thorough treatment of the subject and in particular treats direct effects on fisheries cursorily.

I found the most interesting part of the book to be the reviews of alternative water supply sources. While the book is not a comprehensive treatment of the subject, as is so often the case with such collections of independently written papers, it is a useful compilation of information on California's water supply.—*Harold K. Chadwick*

A Field Guide to the Birds of Mexico

By Ernest P. Edwards; Copyright by Ernest P. Edwards, Sweet Briar, Virginia, 1972, 300 p., 2 maps, 24 color plates. $8.50.

This comprehensive field guide includes the description of nearly 1,000 birds occurring from the northern border of Mexico to the southern border of Nicaragua. Mexico has almost 300 more species than the rest of the North American continent combined. Some 500 species not occurring in the United States are illustrated on 24 color plates. The book is 5¾ x 9 inches and has two maps to assist the observer in becoming acquainted with Mexico and its bird distribution. In addition to the customary discussion and information about each species, the author has added some helpful clues to the identification of birds. Hints in the bird family discussions will help the novice birder on whether to concentrate on color, size, song, range, behavior, or some other feature in the identification of birds in the field.

Most bird species are not found throughout Mexico and the author assists the observer in providing information on the most likely regions they will occur. Those of you who are bilingual will enjoy the description of each species in Spanish. For those bird species not occurring in Mexico but are found in one or more of the Central American countries, a section has been devoted for observers birding further south. The author has already published a companion-book entitled "Finding Birds in Mexico" and should prove useful in locating birding areas.

"A Field Guide to the Birds of Mexico," particularly with its color plates and assistance to the identification of birds in Mexico and Central American countries, will be an asset to travelers birding below the United States borders.—*Robert D. Mallette*

Modern Book of the Black Bass

By Byron Dalrymple; Winchester Press, 460 Park Avenue, New York, N.Y., 1972, 206 p. illus. $6.95.

Dalrymple reviews the subject of modern fishing for black bass in a logical, thorough and easy-to-read fashion. Any angler who wishes to be a successful black bass fisherman in any part of the U.S.A. would do well to read and digest this book.

The author covers the necessary basic information about all the species of black bass to properly introduce the reader to the subject. He describes how man-made lakes of recent times across the nation have created a different habitat from that traditionally described as black bass habitat. In presenting some recent scientific knowledge about the behavior of the black bass, together with dispelling some old ideas, the author clearly shows how the modern angler should keep in mind certain thoughts to catch black bass. The guess-work in fishing for black bass can be eliminated as the author describes the use of modern fishing gear, including some sophisticated electronic devices.

The book is particularly applicable to California, where many man-made lakes exist and the multi-recreational use concept of water has created fishing problems—especially for the black bass fisherman.—*Leon A. Woods, Jr.*

The Stern Trawler

Peter Hjul (Editor), G. C. Eddie, P. D. Chaplain, N. M. Kerr, J. J. Waterman, and John Burgess; Fishing News (Books) Ltd., 23 Rosemount Avenue, West Byfleet, Surrey, England and 110 Fleet Street, London EC4A 2JL. 221 pages, illustrated. £8.50.

An enlightening look at the current direction of world fisheries is provided by this book. Stern trawling, a system long utilized on the west coast of North America, has in recent years been implemented aboard large factory freezer and processing trawlers in other parts of the world; vessels that are capable of fishing anywhere in any ocean for a wide spectrum of resources.

The evolution of the modern factory trawler is traced from the first construction in 1953 through 1971, a period that embraced emperical methods as well as operations research and computer simulation to aid in the design and construction of sophisticated trawlers. Innovative methods in gear design, deck and processing machinery, gear handling, fish processing, and fish preservation that facilitate stern trawling are concisely described.

Future trends and developments in vessels, gear, fish processing and preservation are explored. Recommendations are given to facilitate operations to produce a high quality product.

The book is well-illustrated with photographs and sketches. Commercial and research trawlers from throughout the world ranging from 38 to 420 ft are described.

The reasons for successes and some failures of stern trawlers are considered along with techno-economics of fillet and freezer trawlers. The feasibility of United States factory trawler operations appears dim when considering the inventory given of world trawlers in 1970 of 900 freezer and factory trawlers of over 1,000 tons of which 400 belonged to the USSR, 125 to Japan, 75 to Spain, 50 to West Germany, 40 each to France and Britain; and also the recent failures experienced in the operations of the two U.S. factory vessels described in the book, the *Sea Freeze Atlantic* and the *Sea Freeze Pacific*.

A chapter on small stern trawlers of less than 100 ft, sizes that are successful on the west coast, is very informative.

The authors Peter Hjul, G. C. Eddie, P. D. Chaplain, N. M. Kerr, J. J. Waterman, and John Burgess are experts in their respective fields.

This book will interest a wide audience including fishermen, fish processors, scientists, and laymen.—*Tom Jow*

printed in CALIFORNIA OFFICE OF STATE PRINTING

83935—800 10-72 5,300

POSTMASTER: RETURN POSTAGE GUARANTEED
Editor, CALIFORNIA FISH AND GAME
CALIFORNIA DEPARTMENT OF FISH AND GAME
987 JEDSMITH DRIVE, SACRAMENTO, CA 95819

BULK RATE
U.S. POSTAGE
PAID
Sacramento, Calif.
Permit No. 949

150